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WEATHER BUREAU

Washington, D. C.

ATLAS

OF

CLIMATIC CHARTS OF THE OCEANS

Prepared under the supervision of

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Derived directly and exclusively from original weather observations recorded on ships at sea and collected in the files of the UNITED STATES WEATHER BUREAU

Compiled and summarized in projects of the

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TITLES OF CHARTS

PREFACE

The charts in this atlas have been derived from approximately 5½ million observations taken on ships at sea during a period of more than 50 years. Data from islands and continents have not been introduced; in fact, even the observations in port have been excluded in order that the material (confined strictly to ships' reports collected in the Weather Bureau) may be truly representative of conditions on the open sea. In that respect this volume is unique. Heretofore nearly all charts of this character, which have covered a major portion of the earth's surface, have depended chiefly on observations from islands and continents, and have utilized miscellaneous studies of ships' reports from various sources.

Those who have a practical use for the information presented in these charts will be appreciative of the labors of many thousands of persons who have contributed to the final results. The climate of a major portion of the earth's surface cannot be presented adequately until thousands of observers have gone to their posts daily in all kinds of weather for a long period of years, often without any pay except a word of appreciation from those who collect the observations. In this kind of work the mariner excels because of the nature of his occupation.

Some of the weather observations which have gone into these charts were taken prior to 1880. Since that year they have been arriving in increasing numbers. In the earliest part of the period many observations came from sailing ships, but in later years almost exclusively from self-propelled vessels. Some have been supplied by the navies of the world but the great bulk of the reports has been furnished by merchant ships carrying the flags of every maritime nation.

Even when these millions of observations had been supplied through the cooperation of the mariner, an enormous task lay ahead. Some of the report sheets had only one observation, but the majority contained several which had been taken at different positions during voyages. They had to be separated, transcribed to individual slips or cards, reassembled by months and ocean squares, and then tabulated and summarized. This task was so great that it was impossible for the Marine Division of the Weather Bureau to summarize completely more than a small fraction of the observations as they were received, to say nothing of treating as a whole the mass of reports that had been accumulating for years.

Credit is due to the Civil Works and Works Progress Administrations for supplying the funds to employ competent workers in sufficient numbers to accomplish this great task. Practically all of the work of sorting, compiling, and summarizing the observations was done by persons secured under the ordinary terms of employment in these agencies. Even the preparation of the finished drawings for the lithographer, precisely as they appear in this atlas, was accomplished by employees regularly detailed to the project.

At every stage in the operations the work was supervised by W. F. McDonald, who, at the beginning of the project, was the Chief of the Marine Division of the Weather Bureau at Washington and more recently has been and is now in charge of the forecast and marine center at New Orleans. Every detail of organizing the material and personnel, and of the work of compiling the data in a form suited to charting was developed under his personal direction. Without exception, he also prepared the preliminary charts which were used as copies for the finished drawings. In an appropriate place he acknowledges the assistance of those who were associated with him in the undertaking.

It is hoped that the information revealed in these charts will be of such benefit to navigation of the sea—and the air over the sea—as to justify the patient efforts of the thousands of seamen who have supplied records of the weather on the oceans through these many years.

C. C. Clark,
Acting Chief, Weather Bureau.

Washington, October 1, 1938.

ATLAS OF CLIMATIC CHARTS OF THE OCEANS

By Willard F. McDonald

INTRODUCTION

A number of efforts have been made to show climatic conditions on charts of the world. The Atlas der Meteorologie by Hann, which appeared in 1887, was the first general work to be based on sufficient data to present a reasonably accurate world picture of the distribution of barometric pressure, air temperature, and prevailing winds. Charts were included for the year and for the months of January and July.[1] In the same year there appeared an atlas of marine meteorology[2] which contained Teisserenc de Bort's pressure and wind charts of the globe for January, July, and October.

The famous Challenger Expedition from 1873 to 1876, provided new data and presented an opportunity to assemble material from all available sources, but the report of atmospheric circulation, which resulted from the expedition, did not appear until 1889.[3] This report, edited by Alexander Buchan, contained charts showing the mean temperatures, pressures, and prevailing winds of the globe for the year and also for each of the 12 months.

Buchan was largely responsible for the meteorological charts in Bartholomew's Physical Atlas.[4] Volume III is the Atlas of Meteorology, issued in 1899. It contains more than 400 maps which show winds, temperatures, pressure, and cloudiness, by months, for the world and rainfall, by months, for the continents. In addition, there are many regional maps. In his introduction to this atlas, Buchan listed the more important works that had influenced the progress of meteorology up to that time (1899) as follows: the Theory of the Trade Winds, by Hadley (1735); the Distribution of Heat on the Surface of the Globe, by Dove (1852); the Isobars and Prevailing Winds of the Globe, by Buchan (1868); and the Distribution of the Rainfall of the Globe, by Loomis (1882).

Bartholomew's Atlas has for many years been the standard work. Although an enormous mass of additional records has accumulated, no one during the intervening years has compiled the material in the form of a world atlas of climate of both land and sea in anything like the comprehensive manner in which Buchan compiled and edited Bartholomew's Atlas of Meteorology.

It is appropriate to note that the credit for originating the plan of collecting observations for the oceans is due in a very large measure to Matthew F. Maury. He began a systematic collection of ships' logs in 1841. His work had a profound effect upon ocean commerce of the latter half of the nineteenth century and is the foundation of the pilot charts of the present day. Maury's material formed a very important part of the groundwork of the meteorology of the oceans. His physical geography[5] and sailing directions were celebrated works of the time but do not give an adequate conception of the importance of Maury's labors. One must examine the Pilot Charts of the Hydrographic Office of the present day to understand the practical significance of Maury's efforts.

It is necessary, however, to go back nearly to the beginning of the nineteenth century to find the basis of practical weather records at sea. If seamen had continued to describe the winds and weather in their own terms, or by different scales, the data would have been in a chaotic state, very difficult of reduction to useful averages. In 1806 Francis Beaufort devised a scale of wind force which was revised in 1807 to include in addition to calm, 12 graduations of wind force. His weather notation also appears to have been devised in 1806.[6] Both these scales came into general use. The Beaufort wind scale continues in almost universal use today, without important changes since 1807. The weather notation suffered many changes; for example, the letter "s", originally signifying "sultry", was changed to "hard squalls" between 1820 and 1825, and later was used to indicate "snow." Fortunately, during the period when observations used in this atlas were being taken, there were no important changes in the Beaufort scale of notation and seamen were preparing records with uniform scales for entry of wind and weather which make their records of observations comparable.

Since the publication of Bartholomew's Atlas in 1899, a number of excellent regional climatic maps of the oceans have appeared. Noteworthy examples are the charts of the China Seas[7] and other regions, produced in the Netherlands, and the publications of the Deutsche Seewarte at Hamburg and the British Meteorological Office in London. Data for the North Pacific Ocean have been published by the Imperial Marine Observatory at Kobe. The Pilot Charts of the United States Hydrographic Office contain meteorological data for the navigable oceans of the world.

The charts presented hereafter show the climatic conditions pertaining to the ocean surfaces only. For climates of the continents the reader may consult a considerable number of recent publications[8] which summarize the available land data.

Pronounced geographical and seasonal variations are evident in the phenomena shown on the charts which follow. Continental influences are more effective over adjacent oceans in the Northern Hemisphere than in southern latitudes because the proportion of land to ocean is so much greater north of the Equator. The seasonal march of conditions proceeds in the opposite sense in the two hemispheres.

There are clear evidences, even from a casual inspection, of the interrelations of the various phenomena charted. For example, the season of the southwest monsoon in the region between Africa and India, as shown on some of the charts, is accompanied by a great increase in the frequency of haze, as shown on other charts, undoubtedly the result of fine dust carried from the adjacent continents. On the appropriate charts may be seen the prevalence of fog in certain parts of the northern oceans in summer; other charts show that warm winds blow over relatively cold waters to produce these fogs. The bold elevation of the Andes extending along the entire west coast of South America, together with the adjacent extensive drift of cold water northward in the South Pacific Ocean, form a combination of influences that makes itself evident in many of the charts.

It is not within the scope of this atlas to attempt an explanation of the phenomena and their variations. A careful study of the charts will demonstrate, however, that the observations supplied by seamen have not been careless or perfunctory; otherwise, the seasonal and geographical variations and the interrelations of the various elements would not be so consistently in evidence.

[1] ATLAS DER METEOROLOGIE. BERGHAUS PHYSIKALISCHER ATLAS, Abt. 3. Gotha. 1887.

[2] ATLAS DE METEOROLOGIE MARITIME. Publie a l'occasion de l'Exposition Maritime Internationale du Havre. Paris. 1887.

[3] REPORT ON THE SCIENTIFIC RESULTS OF THE VOYAGE OF H. M. S. CHALLENGER. PHYSICS AND CHEMISTRY. v. 2, pt. 5, Report on Atmospheric Circulation. London. 1889.

[4] BARTHOLOMEW'S PHYSICAL ATLAS. v. 3. Atlas of Meteorology. London. 1899.

[5] Maury, M. F. THE PHYSICAL GEOGRAPHY OF THE SEA. London. 1855.

[6] Garbett, L. G. ADMIRAL SIR FRANCIS BEAUFORT AND THE BEAUFORT SCALES OF WIND AND WEATHER. Quart. Jour Roy. Met. Soc. 52: 161–172. 1926.

[7] Koninklijk Nederlandsch Meteorologisch Instituut. OCEANOGRAPHIC AND METEOROLOGICAL OBSERVATIONS IN THE CHINA SEAS AND IN THE WESTERN PART OF THE NORTH PACIFIC OCEAN. DeBilt. 1936.

[8] Clayton, H. Helm, et al. WORLD WEATHER RECORDS. Smith. Misc. Collect. 79, 1927; v. 90, 1934. Washington.

Kendrew, W. G. CLIMATES OF THE CONTINENTS. Ed. 3, Oxford. 1937.

Köppen, W., and Geiger, R. HANDBUCH DER KLIMATOLOGIE. v. 2, America; v. 3, Europe and Northern Asia; v. 4, Southern Asia and Australia; v. 5, Africa and the Oceans. (In course of publication in parts.)

In addition there are numerous publications on local and regional climatology, including especially the official reports of the various government bureaus throughout the world.

THE OBSERVATIONS

INSTRUMENTS AND METHODS OF OBSERVATIONS

In some respects it is fortunate that the simple routine of weather observation at sea has been standardized through many years without much reliance on instruments other than the barometer and thermometer.

The Beaufort scale of wind force has not been altered in any significant detail in more than a century. Before steam navigation developed the scale was based on the effects of winds on sails; since that time the estimates of Beaufort forces have been derived principally from observations of the effects of the winds on the surface of the sea. The latter are so complex that they have never been satisfactorily reduced to a series of specifications like those for the effects of winds on sails; nevertheless, the relationship between varying wind forces and the appearance of the sea surface seems to be just as accurately fixed in the minds of experienced seamen on steamships as was the effect on sails in the experience of their predecessors.

In only one respect is there evidence of a systematic difference between the wind observations on sailing ships and those on vessels moving under their own power. The number of dead calms recorded is undoubtedly less since steamships have displaced sail, due to the fact that the ship's motion creates air movement on the decks even when the atmosphere is calm, with a corresponding tendency away from the recording of Beaufort 0, the dead calm, which made itself inescapably obvious to the observer on a sailing ship.

The direction of the wind given in ships' weather reports is the true wind and not the apparent wind that results from the combined movements of the ship and the atmosphere. The true direction has usually been determined by observing the effect of the wind on the sea surface. Tables are provided to seamen, however, for calculating the true from the apparent wind.

In general, it is possible to say that observations of wind at sea are the most uniform and most generally reliable data contained in the records treated in this work.

Wind direction has generally been recorded in points of the compass with the eight major points definitely favored over those intermediate. In some instances directions have, however, been recorded in degrees of azimuth, or in code values, or the international scale. All tabulations were made in terms of the 16-point compass, and where there was greater refinement in ships' observations, the record was credited to the nearest point in a counterclockwise sense. For example "NE by E", or "05" in the international figure code, or "56°" in the azimuth scale, was counted as "NE".

Entries of data on wind appear in practically all weather observations at sea, but a small fraction are unserviceable because of illegible or indeterminate character of the entry. For example, the wind was sometimes recorded as "variable" in direction, or from more than one point of the compass; such reports cannot be used statistically in calculating prevailing or resultant directions. All cases of indeterminate wind records were excluded from the compilations.

For observations of temperatures and air pressure, reliance has been placed almost entirely on the instruments carried as a regular part of each ship's equipment, as there has never been in the United States any extensive program for issuing and installing Government-owned meteorological instruments on merchant ships. Some other governments have furnished instruments to ships, some of which have sent reports to the United States and the records have, of course, benefited by such installations.

Barometer readings have been reported in three different units of measurement—inches, millimeters, and millibars. Both mercurial and aneroid barometers have been employed and the basis for accurate correction of older records was often uncertain. The difficulties of dealing with these matters exceeded the abilities and training of the available personnel, hence a decision was made to postpone the compilation of average pressures at sea in order to devote all the energies of the staff to other phases of the enterprise.

Readers interested in isobars over the oceans are referred to Buchan's Charts in volume III of Bartholomew's Physical Atlas.

Although thermometers and their exposures on shipboard have been of variable quality, the problems in connection with observations of temperature were far more tractable than those arising from the pressure data. Shipboard thermometers have been, in the main, well exposed in situations sheltered from the sun. Conditions on a moving ship generally favor good circulation of the air; this is especially important for the wet bulb thermometer, and considerable weight has been given to the wet bulb data. There is, of course, an unknown range of error (usually small) in the individual thermometers from which observations were reported, but it is safe to assume that in such a large mass of observations the errors will tend to balance themselves about the true mean. Therefore, studies of temperatures were made, and certain of the results are presented in this work.

Temperature of the sea surface has been obtained by either of two methods. By the method most frequently used, a canvas bucket was thrown overboard to bring up a sample of water and take its temperature. The other method records the temperature of sea water drawn rapidly into condensers in the engine room through an intake not far below the sea surface. In preparing charts for this atlas, the sea temperatures were all combined into one tabulation without regard to the method of observation employed.

DEFINITIONS AND SCALES

The scale of wind force devised by Beaufort and his letter notations for description of general states of weather were, with few exceptions, used for recording the observations dealt with in this atlas. After 1929 figures of the International Code began to replace the Beaufort weather notation for recording observations on ships that reported by wireless telegraph. Only a small fraction of the total was recorded in the International Code, however, and no noteworthy difficulties in compilation resulted.

The Beaufort scale for wind force is preserved without change in the International Code, hence continuity in use and meaning of this element has not been interrupted at any time within the period of records underlying the work. For ready reference, specifications of the force scale agreed upon by the Conference on Maritime Meteorology at London in 1874 (based upon the handling of a full-rigged sailing ship), together with a description later formulated to show the graduated effects of similar variations in wind speed on land, are given in table 1.

As sailing vessels were displaced by self-propelled ships, seamen of necessity adopted other grounds of judgment than the action of the wind on sails, but the transition was gradual, and there is no evidence whatever that the meaning of the Beaufort graduations suffered any change. One authority,[9] in a discussion of this matter, says:

> The sailor's estimate of the wind as used in his ordinary conversation is based on its effect on his surroundings, on the waves formed on the surface of the sea, on the amount of broken water, on the sound produced as it blows through the rigging, and on the way his ship can stand up to it. These terms are understood by all experienced sailors and are quite independent of any scientific definitions. The rig of ships has changed, sail has been replaced by steam, but the effect of the wind on the sea has remained, and will always remain, exactly the same. The sailor's description of the strength of the wind being based on effects independent of the rig of his ship has survived all the changes in marine transport.

[9] Simpson, Sir George C. THE VELOCITY EQUIVALENTS OF THE BEAUFORT SCALE. Brit. Met. Off. Prof. Notes No. 44. 1926.

TABLE 1.—*Specifications of the wind force scale agreed upon by the Conference on Maritime Meteorology at London in 1874* [1]

Beaufort No., international	Beaufort's designation of wind	Deep-sea criterion, 1874, international	Specifications of Beaufort scale for use on land, based on observations made at land stations
0	Calm		Calm; smoke rises vertically.
1	Light air	Just sufficient to give steerage way to a full-rigged ship.	Direction of wind shown by smoke drift, but not by wind vanes.
2	Light breeze	That in which a well conditioned man-of-war with all sail set and clean full, would go in smooth water from 1 to 2 knots.	Wind felt on face; leaves rustle; ordinary vane moved by wind.
3	Gentle breeze	That in which a well conditioned man-of-war with all sail set and clean full, would go in smooth water from 3 to 4 knots.	Leaves and small twigs in constant motion; wind extends light flag.
4	Moderate breeze	That in which a well conditioned man-of-war with all sail set and clean full, would go in smooth water from 5 to 6 knots.	Raises dust and loose paper; small branches are moved.
6	Fresh breeze	That to which she could just carry in chase, full and by, royals, etc.	Small trees in leaf begin to sway; crested wavelets form on inland waters.
5	Strong breeze	That to which she could just carry in chase, full and by, topgallant sails.	Large branches in motion; whistling heard in telegraph wires; umbrellas used with difficulty.
7	Moderate gale	That to which she could just carry in chase, full and by, topsails, jib, etc.	Whole trees in motion; inconvenience felt when walking against wind.
8	Fresh gale	That to which she could just carry in chase, full and by, reefed upper topsails and courses.	Breaks twigs off trees; generally impedes progress.
9	Strong gale	That to which she could just carry in chase, full and by, lower topsails and courses.	Slight structural damage occurs (chimney pots and slates removed).
10	Whole gale	That with which she could scarcely bear lower maintopsail and reefed foresail.	Seldom experienced inland; trees uprooted; considerable structural damage occurs.
11	Storm	That which would reduce her to storm staysails.	Very rarely experienced; accompanied by wide-spread damage.
12	Hurricane	That which no canvas could withstand.	

[1] From The Meteorological Glossary. London. 1930.

Since estimates of wind force in the Beaufort scale rest upon the common experience of men at sea, and are based upon the total effect produced by the atmosphere in motion rather than on measurement in a particular spot, there is an essential difference between Beaufort estimates and measured wind speeds. Many efforts have been made to formulate Beaufort values in terms of miles per hour, meters per second, or knots, with varying success, and in the very nature of the case, any scale of conversion will leave something to be desired.

Nevertheless, the conversion of average Beaufort values into a linear scale of wind speed makes for the readier comparison of variations in wind movement over different parts of the oceans. Average Beaufort forces have, therefore, been evaluated and charted as equivalent speeds in knots. The conversion table used (which was obtained by adjustment within the values given by the Smithsonian Meteorological Tables, edition of 1931, for average Beaufort equivalent in knots) is shown in table 2.

TABLE 2.—*Conversion from mean Beaufort values for wind force, to speed in knots*

(Adapted from table 39, Smithsonian Meteorological Tables, edition of 1931)

Mean values, Beaufort scale	Speed in knots	Mean values, Beaufort scale	Speed in knots
1. 2 or less	Less than 2	4. 0–4. 1	14
1. 3–1. 5	3	4. 2–4. 3	15
1. 6–1. 8	4	4. 4–4. 6	16
1. 9–2. 1	5	4. 6–4. 7	17
2. 2–2. 4	6	4. 8–4. 9	18
2. 5–2. 7	7	5. 0	19
2. 8–2. 9	8	6. 1–5. 2	20
3. 0–3. 2	9	5. 3–5. 4	21
3. 3–3. 4	10	5. 5–5. 6	22
3. 5–3. 6	11	5. 7–5. 8	23
3. 7–3. 8	12	5. 9–6. 0	24
3. 9	13	6. 1	25

The Beaufort weather notation in the form agreed upon in 1874 is given below. Beaufort's original weather notation was frequently changed in the early years, and only five letters retain their original meanings until this day. It may be assumed, however, that by virtue of the agreement in 1874 the meanings were well standardized in the observations underlying this atlas, which are for the most part dated later than 1885.

Beaufort weather notation

b. Blue sky.
c. Cloudy sky (detached clouds).
d. Drizzling.
f. Fog.
g. Gloomy.
h. Hail.
l. Lightning.
m. Mist.
o. Overcast sky.
p. Passing showers.
q. Squally.
r. Rain (continuous).
s. Snow.
t. Thunder.
u. Ugly threatening sky.
v. Exceptional visibility.
w. Dew.
z. Haze.

A strong point in the usefulness of the Beaufort weather notation consists in the ease with which letters can be combined to make a comprehensive description of a complex weather condition. For instance, should an observer have an overcast sky with rain and distant lightning, but no thunder heard, the whole situation is described by using the combination, "orl." To describe passing showers from clouds broken with patches of blue sky, attended by exceptional clearness in the lower atmosphere, the three letters, "epv," suffice. The records contain a vast number of such combination entries; this fact supports the belief that seamen have, as a rule, been careful to record their whole impression of the general weather situation attending the other more particular matters of observation.

While satisfactory uniformity can be attributed to records in the notations under discussion, it would be erroneous to assume that the international definitions have at all times been applied with complete precision. Some difficulties deserve brief mention.

The definitions for "fog," "mist," and "haze" prescribe certain limits of visibility as criteria for use of the terms. Fog and mist are defined as due to the presence of microscopic droplets of condensed moisture; the condition is described as "fog" when objects cannot be seen at a distance of 1,100 yards, and "mist" when visibility is from 1,100 to 2,200 yards. Haze is defined as generally due to microscopic particles in the atmosphere, such as smoke, dust, or salt, with visibility 1,100 to 2,200 yards.

There is good ground for the belief that seamen, like landsmen, put less definite meanings into these three terms, so that, in the collected masses of observations, "fog" becomes roughly equivalent to the "dense fog" or "moderate fog" of the continental meteorologist; "mist" is similar to "light fog"; and "haze" is used to record either of two distinct conditions, one of which is dry haze and the other resembles a very light mist in that it is attributable to moisture rather than dust. Haze is capable of producing obscuration in almost any degree; it often admits of visibility far beyond 2,200 yards, but dust haze on land is sometimes more dense than the densest fog. A slight impairment of visibility can be caused by true haze attended by unmistakable evidences of dustiness, but haze is probably as commonly recorded when moisture or unsteadiness in the lower atmosphere is the causative agent.

The points to be emphasized are, that records of "haze" as they appear in ships' observations cannot be interpreted as clearly as those of "fog" and "mist"; and also that the prescribed criteria in terms of distance have not been rigidly applied in use of any of the three terms.

"Exceptional visibility" in the Beaufort notation has no exact definition. Ships' observers have been instructed to make this record whenever distant objects (or the horizon) are more sharply defined than usual, indicating exceptional clearness as well as exceptional steadiness of the lower atmosphere.

Due to the fact that stormy winds and spray often attend precipitation at sea, the measurement of the quantity of rainfall on shipboard is not generally feasible. Underscoring the rain symbol in the record indicates heavy intensity, but such distinctions are not statistically useful and the studies herein are confined to the mere occurrence of the designated rainy condition regardless of intensity.

The three terms, "rain", "drizzle," and "passing showers" for various types of rainfall, seem to have been for the most part applied with a satisfactory degree of uniformity by seamen. The distinction between "rain" and "drizzle" is one depending on the size of the drops. "Passing showers" are defined as of brief duration, in contrast with the more continuous character of the steady forms of rain.

There is in the records conclusive evidence that shipboard observers have not adhered to strict uniformity in use of the Beaufort symbols for showers and snow. The letter symbol "s", which should be confined to observations of snow, is sometimes found in reports from tropical latitudes where snow at sea level is an impossibility. This makes it clear that the symbol was recorded erroneously to represent "showers", instead of the proper symbol "p" for "passing showers". There is also evidence that the letter "h" has occasionally been used for "haze" instead of "hail", to which it properly belongs.

Cloud forms have been entered with remarkable regularity in ships' records, and the cloud symbols are, as a rule, intelligible. The following abbreviations were commonly used:

Cloud forms	Usual abbreviations [1]	Alternate abbreviations
Cirrus	Ci	(C)
Cirro-stratus	Ci. St	(CS)
Cirro-cumulus	Ci. Cu	(CK)
Alto-stratus	A. St	(AS)
Alto-cumulus	A. Cu	(AK)
Cumulus	Cu	(K)
Strato-cumulus	St. Cu	(SK)
(Cumulo-stratus)	(Cu. st.).	
Stratus	St	(S)
Nimbus	N. (Nb., Ni.)	(N)
(Fracto-nimbus)	(Fr. N.)	
Cumulo-nimbus	Cu. Nb	(KN)
(Nimbo-cumulus)	(N. Cu.)	

[1] Abbreviations in parentheses represent a system of notation used to a considerable extent in some of the earlier records.

Temperatures have been reported in Fahrenheit, centigrade, and Réaumur scales; all readings were converted to the Fahrenheit scale for purposes of compilation. Wet bulb temperatures appear in a minor part of the observations but no relative-humidity values have been reported or compiled. The depression of the wet bulb has been dealt with, however, and for reference table 3 of relative humidities covers the range of temperature data shown on charts in this atlas.

TABLE 3.—*Relative humidity at different Fahrenheit temperatures*

Air temperature (°F.)	Relative humidity when the depression of the wet bulb thermometer is—					Air temperature (°F.)	Relative humidity when the depression of the wet bulb thermometer is—				
	1°	2°	3°	4°	5°		1°	2°	3°	4°	5°
	Percent	*Percent*	*Percent*	*Percent*	*Percent*		*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
28	88	76	65	54	43	58	94	88	83	77	72
30	89	78	67	56	46	60	94	89	83	78	73
32	89	79	59	59	49	62	94	89	84	79	74
34	90	81	71	62	52	64	95	90	84	79	74
36	91	82	73	64	55	66	95	90	85	80	75
38	91	83	75	56	68	68	95	90	85	80	76
40	92	83	75	68	60	70	95	90	86	81	77
42	92	85	77	69	62	72	95	91	86	82	77
44	93	85	78	71	53	74	95	91	86	82	78
46	93	86	79	72	65	76	96	91	87	82	78
48	93	86	79	73	66	78	96	91	87	83	79
50	93	87	80	74	67	80	96	91	87	83	79
52	94	87	81	75	69	82	96	92	88	84	80
54	94	88	82	76	70	84	96	92	88	84	80
56	94	88	82	76	71	86	96	92	88	84	81

THE COMPILATION

The project began in 1934 with 6 months of activity under the Civil Works Administration, during which time more than 2 million marine observations were converted to punch cards for machine tabulation, and an equal or greater number of manuscript observations were brought into sorted and organized files, thus making available for compilation and study most of the Weather Bureau marine records then in hand.

In 1936 and 1937 the Works Progress Administration (successor to CWA) adopted and financed in Louisiana a new project employing more than 200 workers, who added to the previously organized material about 750,000 transcriptions of ocean weather observations for several of the later years and provided a staff for exhaustive treatment of all the observations upon which the charts in this atlas are based.

NUMBER OF OBSERVATIONS

The Weather Bureau material used in this atlas comprises a total of 5½ million individual weather observations, mainly dated between 1885 and 1933. The observations have been gathered from all corners of the traveled ocean areas and from ships sailing under many flags, although the United States, Great Britain, the Netherlands, France, Germany, and Japan have been the major contributors.

There is an extremely wide variation in the volume of observations in different sea areas. The North Atlantic is much the richest in material; the extratropical North Pacific ranks next, but the volume of observations diminishes to relatively low values over large areas elsewhere and also in parts of the northern oceans.

In order to make clear this variation in volume of observational material, a recapitulation is given in table 4, by months and oceans, and a more detailed showing of the distribution of observations will be found on charts 1 and 2, which carry values for each 5-degree subdivision for which data were available. The first gives the grand total of observations for all months of the year, and the second the largest and smallest monthly totals to be found in each unit area.

The millions of weather observations treated involve many times as many items of information, inasmuch as each complete report includes date, time, and ship's position, together with observations of wind direction and force, temperature of air, sea, and wet bulb, general state of weather, amount and kind of clouds, and often other miscellaneous items.

Not all observations are complete in every detail. Wind data appear in nearly all. Air and sea temperatures and estimates of cloud amount are present in about 90 percent of the reports. Records of cloud forms and general types of weather conditions are somewhat less numerous, while wet-bulb readings are shown in much less than half of the observations.

Taken altogether, it is estimated that more than 40 million separate items of data were treated in the course of the work underlying this atlas, many of them over and over in various connections.

METHODS OF COMPILATION

A question will immediately present itself to the scientific mind: How can such masses of observational material be handled by a temporary organization of people, not especially trained for critical analysis, to produce statistical results of scientific value? The answer lies in the method used.

The whole operation was broken down to elemental steps, each supported by a simple working form, so that rank-and-file workers followed simple tasks that became practically automatic in performance. Every phase was thoroughly checked and safeguarded; all computations were run at least twice to assure accuracy. If an item of data was, on the face of it, open to reasonable doubt, either because of its indistinctness in entry on the record or through obvious departure from the data associated with it in time or place, that item was not included in the compilation.

Only the records of observations taken at or near the single hour, Greenwich noon, were admitted to the compilation. To facilitate interpretation with reference to the corresponding local time, which varies with longitude, the local scale of time corresponding to Greenwich mean noon is shown at the bottom border of each chart.

TABLE 4.—*Recapitulation of total GMN observations, by month and ocean area*

Ocean	January	February	March	April	May	June	July	August	September	October	November	December	Annual	Number of 5-degree squares
North Atlantic	315, 633	288, 222	318, 489	314, 675	318, 087	310, 418	312, 694	307, 774	310, 356	331, 930	318, 175	313, 340	3, 759, 793	221
South Atlantic	26, 948	24, 765	29, 003	26, 841	27, 471	24, 137	25, 514	26, 973	24, 296	24, 651	24, 687	26, 628	311, 914	138
North Pacific	75, 530	71, 600	78, 331	77, 800	80, 496	79, 139	81, 408	82, 042	81, 419	81, 710	78, 597	77, 918	945, 990	351
South Pacific	20, 703	19, 838	21, 000	18, 753	17, 991	18, 183	19, 280	19, 217	18, 347	19, 685	20, 954	23, 294	237, 245	378
North Indian	10, 278	9, 709	11, 564	11, 784	11, 872	10, 528	11, 205	11, 394	10, 531	10, 610	10, 171	10, 311	129, 967	62
South Indian	8, 662	7, 616	7, 915	7, 675	7, 578	8, 098	8, 353	7, 905	7, 044	7, 121	6, 939	7, 384	92, 290	165
Total	457, 754	421, 750	466, 302	457, 528	463, 495	450, 503	458, 454	455, 305	451, 993	475, 707	459, 523	458, 875	6, 477, 189	1, 315

FREQUENCY ISOGRAMS

Most of the charts carry isograms that express the "percentage frequency" of the meteorological element depicted.

In each unit area, for each month or season, there was available a definite number of observations. The percentage of this total that showed reports of a particular occurrence was computed. For example, if in a certain area the season from June to August had a grand total of 1,000 observations, and of these 220 showed fog, the percentage frequency is 22. Similarly, if in another area with 2,000 observations, 40 show wind forces of Beaufort 8 or higher, the percentage frequency for gales of force 8 or more is 2.

These percentage values were all placed on work charts in proper position, and lines were drawn through points of equal percentage, at intervals of 5 or 10 percent. These lines were transferred to finished drawings and the enclosed areas then shaded to depict graphically the relative frequencies in various regions. Where charts carry a minimum line for frequency of 1 percent, the areas in which frequency is lower than this value are usually labeled "Few or None."

Although the observations are all confined to a single hour of the day, the diurnal variations are generally small over the oceans and the frequency values may be interpreted as the "chance of occurrence at any hour."

Three-fourths of the charts carry isograms derived from unsmoothed means; the remainder are based upon smoothed values which are averages of four adjacent squares, set down at the central point; this process smooths by increase of area and also by successive overlaps, both in longitude and latitude.

Charts on the following subjects are based on data smoothed by fours in the manner described: Gales of Beaufort force 7 or higher; exceptional horizontal visibility; rain forms; thunder and lightning; depression of the wet bulb; and cirriform clouds.

EXPLANATION OF THE CHARTS

As far as possible, the charts have been made self-explanatory, but close students of the data will raise many questions which cannot be answered by brief legends. Several major points, affecting the meaning of all the climatic charts, are summarized below, followed by a somewhat more detailed discussion of the several classes of data covered in the atlas.

1. In general the charts are based on observations taken at or near Greenwich mean noon. The local time varies according to longitude; local time corresponding to Greenwich noon is, therefore, shown at the bottom margin of the chart base.

2. Charted data are not extended in high latitudes to the extreme limit of the field of observations. Computations were made in all squares having 15 or more observations in the monthly totals, but such weak material was regarded as trustworthy only when *supported in all directions* by surrounding values. Therefore, the northern and southern margins of charted data actually lie inside the extreme limits of observation.

3. The data used for charting were carefully limited to reports from ships actually at sea; where identifiable, the observations recorded while in port were excluded. Compilations are based upon relatively large unit areas, 5° in longitude by 5° in latitude. For these reasons the charts do not portray minor details (often locally important) of the climatic conditions near coast lines.

Special comments relating to the several classes of climatic data studied in detail are given below in an effort to anticipate some of the many questions that will naturally arise in the minds of careful students.

STUDIES OF WINDS

The values for winds are based upon the total number of *serviceable* wind observations and not, as is the case with the studies of frequency of weather and cloud types, upon the total number of observations.

Charts 3 to 14 show average wind directions and forces under the designation "predominant winds." Predominance has been judged in relation to the quarter (90°) showing the most winds. This is not equivalent to the term "prevailing wind," the meaning of which is usually restricted to the single point of the compass that shows highest wind frequency. This matter will be made clearer in the following description of the construction of charts 3 to 14, inclusive.

In producing charts 3 to 14 the tabulations for each 5° unit area to 16 points of the compass were reduced to percentages. These were then carefully examined to ascertain the quarter or quarters (groups of four contiguous points of the compass) which held the largest fraction of the total wind rose. Where entirely separate quarters yielded virtually equal percentages, note was made of the value for each quadrant in order that the fact might be borne in mind in drawing the final arrows.

A single median arrow was entered in each square on the chart to show the point of the compass that best represented the prevailing quarter. Where the percentage frequency of winds thus represented was found to be 80 percent or over, indicating high constancy of wind direction, the shaft of the arrow was doubled, and as the percentage values decreased, three graduations downward were used. A broken arrow was adopted as the symbol for lowest directional constancy where 40 percent or less of the total wind records lay within the quarter indicated.

When all of the wind arrows were laid out in this manner for any given month, the agreement in adjacent areas was so striking, especially in regions where winds show high constancy, that it was a simple further step to produce more generalized lines of best fit which have been depicted on the charts as the predominant wind directions over the ocean areas. These generalized lines have also been drawn to show varying degrees of directional constancy. The intensity varies from double lines, where more than 80 percent of the winds lie within 45° of the indicated median, to broken lines representing winds that blow less than 40 percent of the time within the quarter thus indicated.

The whole wind rose was reduced to a single arrow only when one outstandingly predominant quarter was found in the records. In many squares two and sometimes three arrows representing diverse quarters with virtually equal wind frequency were set down. Such multiple arrows were found grouped in many areas and their presence led to the construction of overlapping lines of generalized wind directions indicative of the alternation or succession in such regions, of two or more fairly distinct wind systems of sufficient frequency or permanence to make their appearance in these statistical results. The system of graphics developed in these charts, therefore, portrays important facts that are lost in the more rigorous treatment of wind records by reduction to resultants, or by selection of a single *prevailing* direction.

Shadings in two colors have been added to the charts of predominant wind directions (charts 3–14) to distinguish areas dominated (60 percent or more of the time) by "lighter" or "stronger" winds, regarding as light winds those recorded as blowing with force 0 to 3, with winds of Beaufort force 4 and above in the stronger bracket.

The records were subjected to further careful analysis in order to obtain for each unit area the computed resultant wind for each month. This was done by giving proper weight to the frequency and average force recorded at each point of the compass, making a graphic summation of vectors on plotting paper and carefully scaling off the resultant direction and force. Twelve monthly charts (Nos. 15–26) carry these resultant directions as arrows plotted for each square, with resultant velocities indicated by shading, scaled in terms of Beaufort force units.

The general similarity between the *resultants* and the more roughly calculated *predominant directions* is worthy of notice. There is, as might be expected, also a marked degree of similarity between areas of higher or lower *resultant* velocity and those depicting the predominance of "higher" or "lower" wind forces in the first set of charts.

A set of seasonal charts (Nos. 27–30) shows the mean wind velocity in knots over the oceans. These were obtained by the use of table 2 for converting average Beaufort force to its equivalent in knots.

No discussion of winds would be complete without suitable reference to the occurrence of calms and the frequency of gales, which have special importance for ocean navigation. Data on the occurrence of dead calms, Beaufort 0, are presented in four charts (Nos. 31–34). Gales are shown in two sets of charts (Nos. 35–50).

From the point of view of air navigation over the oceans, and particularly of flying operations from floating platforms such as aircraft carriers, winds of Beaufort force 7 are today regarded as the limiting velocity. For this reason monthly studies were made of the frequency of winds reaching force 7 and higher velocities (charts 35–46).

Since, however, the long-accepted definition of gales of importance to general surface navigation used Beaufort force 8 as the limit, another set of charts (Nos. 47–50) treats the frequency of winds of Beaufort 8 and higher, by seasons. Included in these latter charts are roses to show the distribution of such gales to eight points of the compass, based upon unit strips 5° in latitude and 20° in longitude, with the rose located at the center of each strip.

VISIBILITY FACTORS

Modern navigation, more than ever before, is concerned with visibility factors over the oceans. Special care was taken to extract all information bearing upon fog, mist, haze, and the occurrence of exceptional horizontal visibility. The frequency of each of the conditions as reported in Beaufort symbols in the records from ships is depicted seasonally in charts 51–66.

Several points of indefiniteness or uncertainty attributable to the records of visibility factors are discussed above, in connection with the Beaufort weather notations (p. V). In the major sense, however, the records are trustworthy indices to important elements in atmospheric conditions that affect navigation over the oceans, and particularly as bearing on the operation of aircraft.

The charts of haze (Nos. 59–62) reveal the mixed character of the conditions reported under that designation. The areas of highest incidence are in all cases located where desert dust is readily carried to sea in the prevailing winds. There are, however, many areas far removed from sources of dust or smoke which show haze with considerable frequency, and it must be assumed that some conditions of atmospheric instability and moisture contribute a minor part of the records of haze at sea.

In connection with charts 63–66, based on the Beaufort symbol "v," it might be assumed that exceptional horizontal visibility would be noted much more commonly by ships' navigators making landfalls, especially at night when navigation lights are observed. The general appearance of the charts, however, indicates that there is no serious distortion in frequencies along coast lines in areas where Greenwich noon observations are taken at night.

CLOUD FORMS

Twenty-eight charts (Nos. 67–94) are devoted to the study of clouds. The average amount of cloud cover produced by all forms of clouds taken together is depicted seasonally, and supplementing these are studies of the frequency with which various cloud forms occur in the observations.

In a note on the face of the charts depicting the distribution of high and middle cloud forms, attention is called to the unavoidable influence of intervening low clouds upon this class of observations.

All cirriform clouds are massed on one set of charts, and middle clouds (alto-cumulus and alto-stratus) on another; but low clouds, having a more important bearing upon aerial navigation over the oceans, are shown in greater detail. Low clouds are separated into four classes: (1) cumulus; (2) stratus and strato-cumulus taken together as similar types commonly producing overcast conditions; (3) cumulo-nimbus, because of its value as an indicator of the most vigorous form of local convection; and finally (4) nimbus, which is indefinite as to true cloud form but offers an interesting parallel for the next succeeding set of charts showing the frequency of rain.

Examination of the records indicates that cloud types were recorded in not more than two-thirds of the observations. The percentage values for frequency have been based on the total number of observations in hand, whether cloud forms were reported in them or not; hence the true frequency of occurrence is undoubtedly considerably higher than the values given on the charts. However, the charts provide a useful indication of the variation from place to place in the incidence of a given cloud type over the oceans.

Comment should be made, however, regarding one noteworthy discrepancy which appears on the charts showing frequency of cirriform clouds. Cirrus is shown as being much less frequent over the Pacific Ocean than over the Indian and Atlantic Oceans. This discrepancy probably arises from the difficulties of observing cirriform clouds at night, since the region of deficiency lies mainly in the zone where Greenwich noon corresponds to night hours in local time.

Similar discrepancies do not appear on the charts of other cloud types, hence it must be assumed that clouds at lower levels are observed at night more readily and accurately than the high clouds.

RAINFALL AND THUNDERSTORMS

No measurements of the amount of rainfall at sea are available in the records treated, but the Beaufort notations were serviceable with respect to the occurrence of steady rain, passing showers, and drizzle. They were also useful in indicating the frequency of thunder and lightning.

Because of the confusion of meaning in the use of the symbol "s" (previously discussed in connection with the Beaufort weather notation), it has not been thought advisable to chart the material which purports to show the occurrence of snow, and it is probable that the material charted under the heading "passing showers" is somewhat deficient because the mistaken entries of "s" for showers have necessarily been excluded.

Dependence can be placed, however, in the relative index value of isograms for the various rain forms depicted in charts 95–106, and especially in the first four showing the combined frequencies of all forms of rain. The latter should be compared with the preceding set, showing the distribution of nimbus cloud observations.

The radical differences between the geographical distributions of the several rainfall types made it advisable, however, to show (in charts 99–106) separate studies of the occurrence of steady rain, recorded as Beaufort "r", as distinguished from passing showers, "p", since these two types of precipitation are quite distinct.

The charts of the occurrence of thunder and lightning (charts 107–110) should be interpreted in the light of the fact that the use of the symbol "l" for visible lightning, in addition to the symbol "t" for audible thunder, greatly increases the range of observation in areas where Greenwich mean noon corresponds to night-time hours. It is not believed, however, that this tendency to distortion is highly important. Certain incomplete studies of Greenwich midnight observations, results from which are not published, bear out the main features of these charts based upon Greenwich noon material.

STUDIES OF TEMPERATURES

Only one phase of the temperature records, the average depression of the wet bulb, is treated on a world scale, in charts 111–114. Wet-bulb observations appear in a minor fraction of the total number, with the result that averages are based on meager data over most of the charted areas. Nevertheless, since very little is known of humidity over the oceans, it was deemed advisable to show the results on the charts. The basic averages of depression of the wet bulb, computed by months and 5-degree unit areas, had to be smoothed by fours in the manner heretofore described, and combined in 3-month seasons, before isograms of reasonable regularity could be obtained.

For the North Atlantic and North Pacific Oceans, the data were adequate for credible monthly means of air temperature and temperature of the sea surface. These are shown in charts 115–126. Data were generally too meager over the other oceans to warrant computation of similar averages for those regions.

Some idea of relative humidities over the northern oceans can be obtained from data on charts for air temperature and depression of the wet bulb. Table 3 facilitates such calculations.

Seasonal differences between sea and air temperature, derived from the monthly values over the northern oceans, are shown in charts 127–131.

Special studies of the relation between Greenwich noon and Greenwich midnight observations, based on almost half a million records, show that there is a daily variation of about 3° F. in observations of the air temperature taken on shipboard. Deck heating under the sun tends to produce temperatures at midday or in the afternoon which average about 3° F. higher than those taken between midnight and dawn. A smaller variation of similar character is found in the average values for sea-surface temperature; it appears to have a range of about 1° F. Charts representing the difference between sea and air temperature have not been corrected for these factors, but in any case the more important features, especially where air is much cooler than water, would not be materially altered by such corrections.

ACKNOWLEDGMENTS

For support and encouragement throughout the whole progress of this work from its inception at the beginning of 1934 until its completion, the writer makes grateful acknowledgment to the late Chief of the Weather Bureau, W. R. Gregg.

The material assistance rendered by I. R. Tannehill, Chief of the Marine Division of the Weather Bureau, in constant review of plans and results and in offering constructive criticism and suggestions has been of great value; acknowledgment is also due to Willis E. Hurd, and other members of the Marine Division staff, many of them my former associates, for accepting without complaint a heavy burden of increased work resulting from the demands of this project for records from the central office files.

It should be repeated here that the results could not have been obtained except by aid of large grants of finance from the President's Emergency Relief Program, which, first under the form of the Civil Works Administration, provided means for 6 months of preliminary activity; and, afterwards, under the Works Progress Administration of Louisiana, supported the much more difficult work that actually brought forth an extensive body of summarized material from which this publication selects only the most general parts.

Under the capable leadership of Leslie Smith, the W. P. A. project supervisor at New Orleans, a body of workers, at times numbering as many as 250, was organized and directed through the troublesome details involved in summarizing the tremendous volume of observations on which the work rests. Thanks are due, not only to Mr. Smith and the exceptional capacity and understanding which he brought to our problems, but also to many individual workers who displayed vision and enthusiasm, as well as faithful endeavor, in the performance of their tasks.

Chart 1

Chart 2

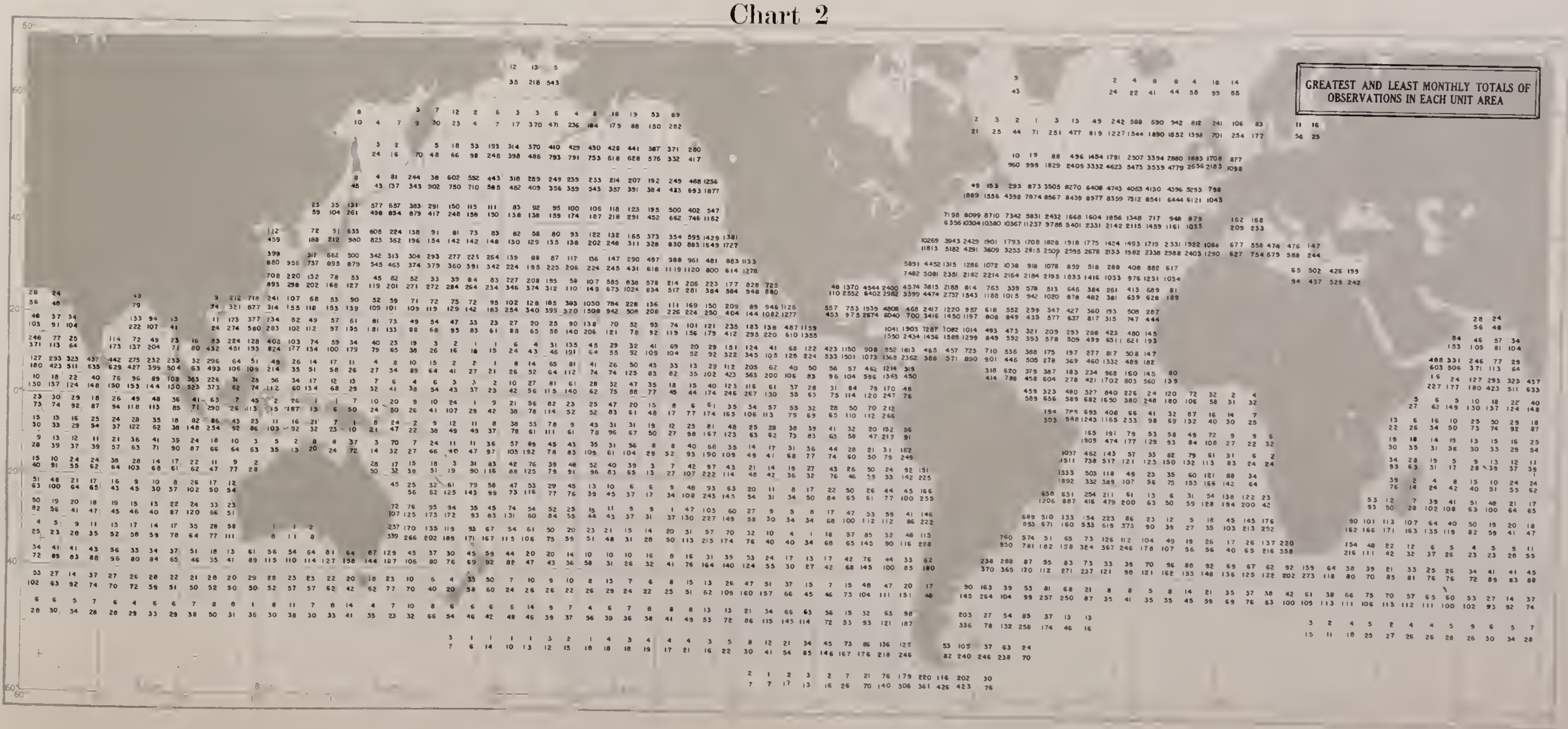


Chart 3

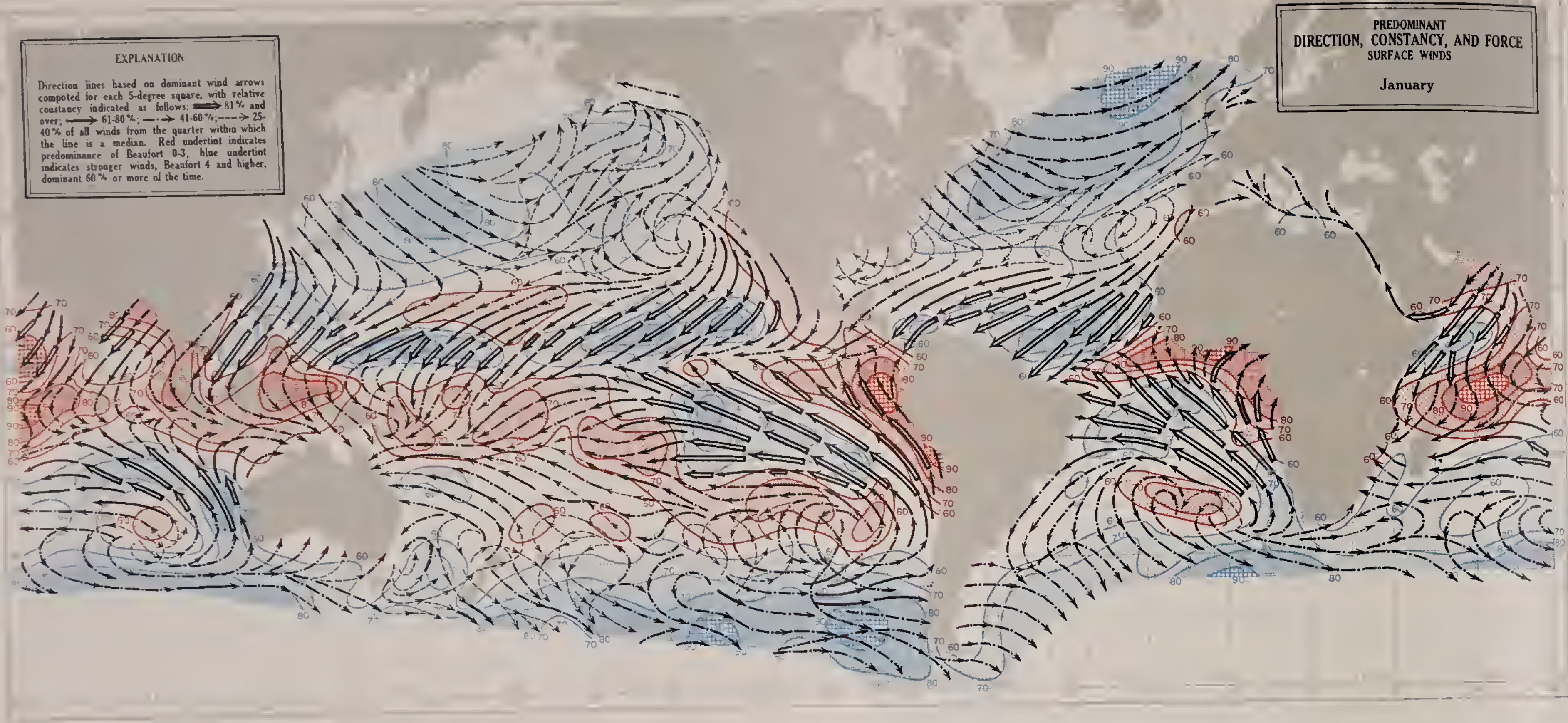
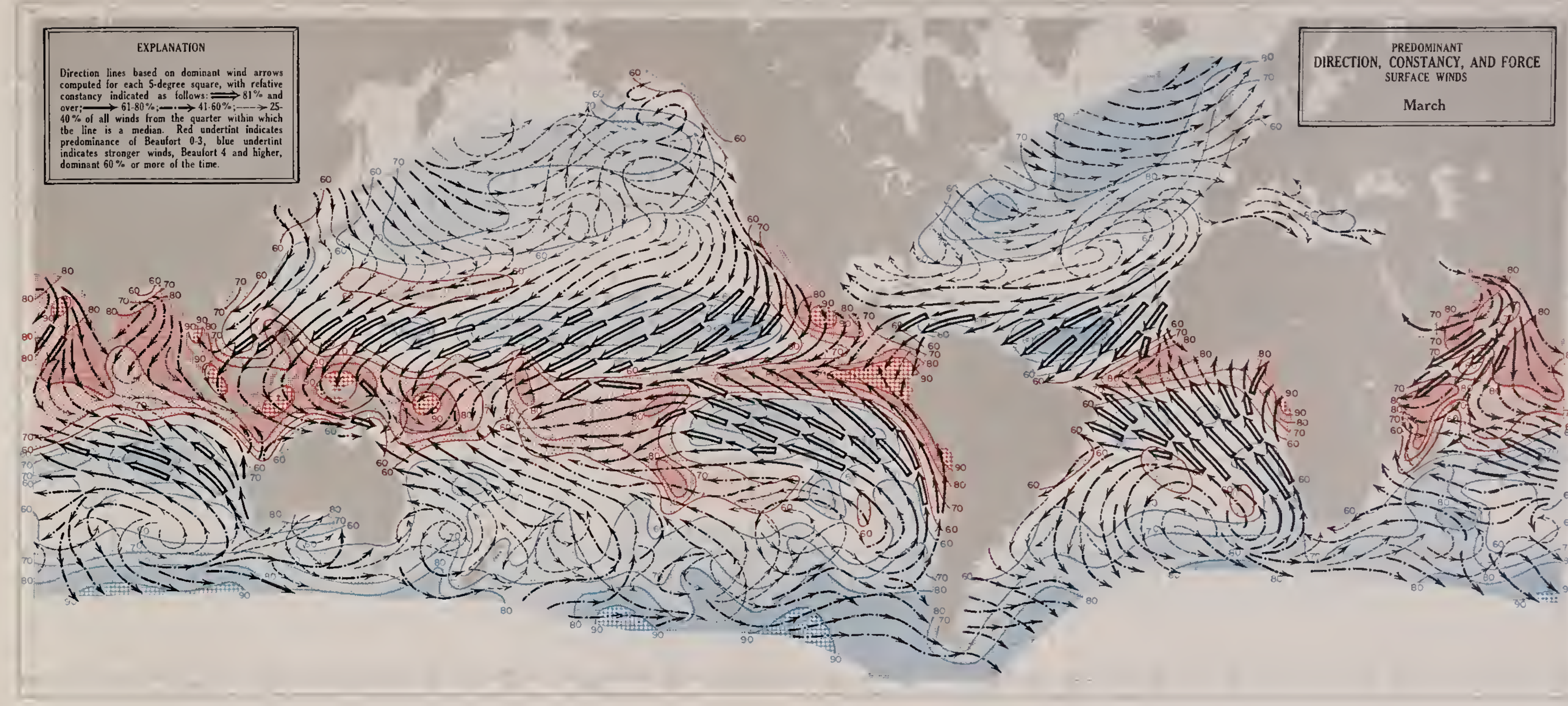


Chart 4

Chart 5



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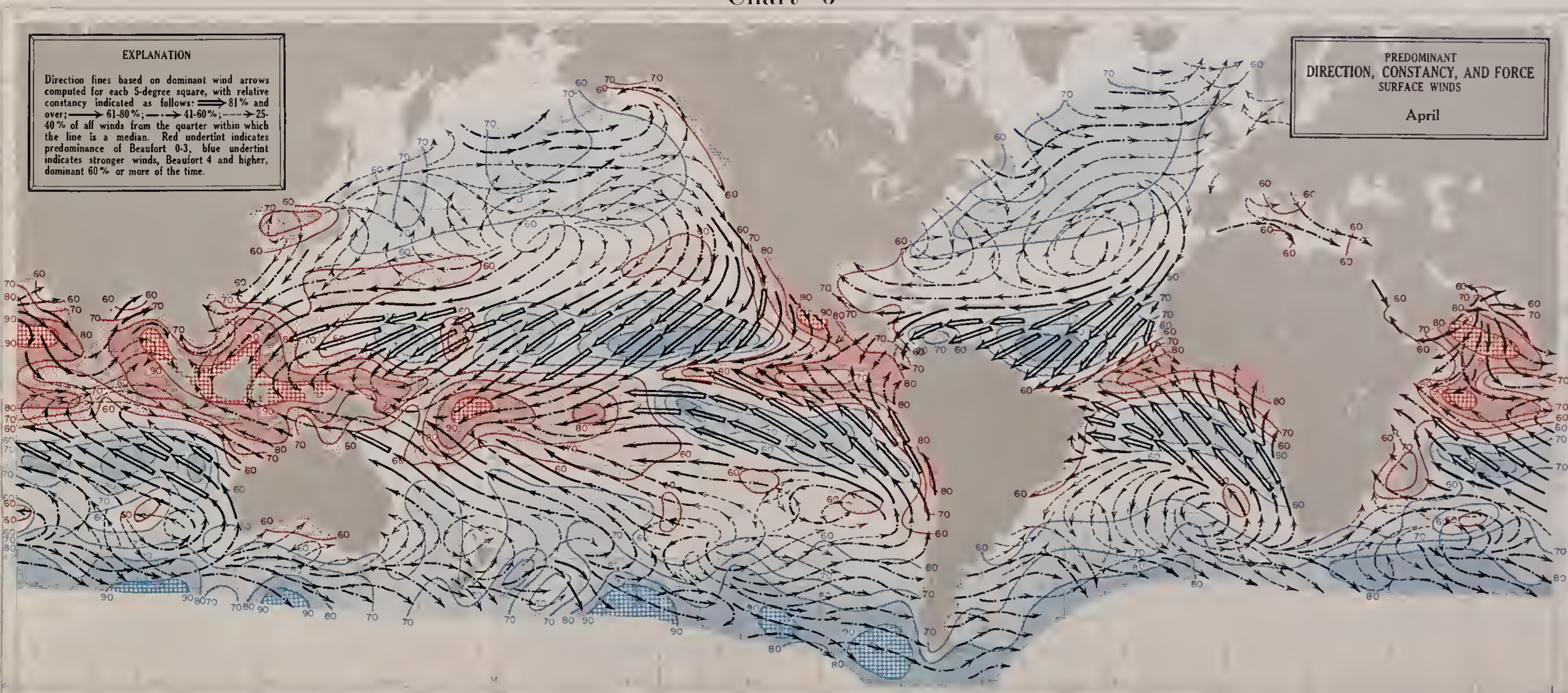

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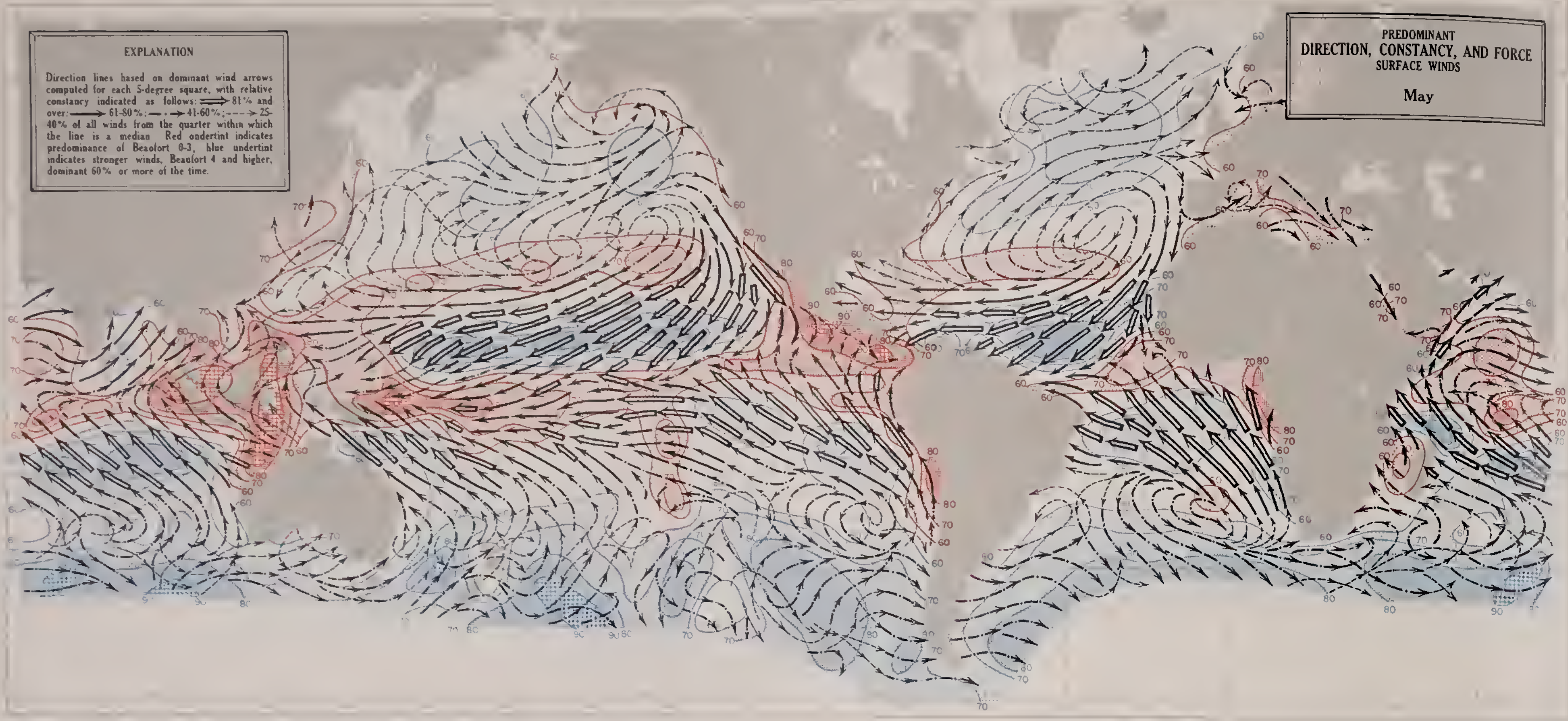

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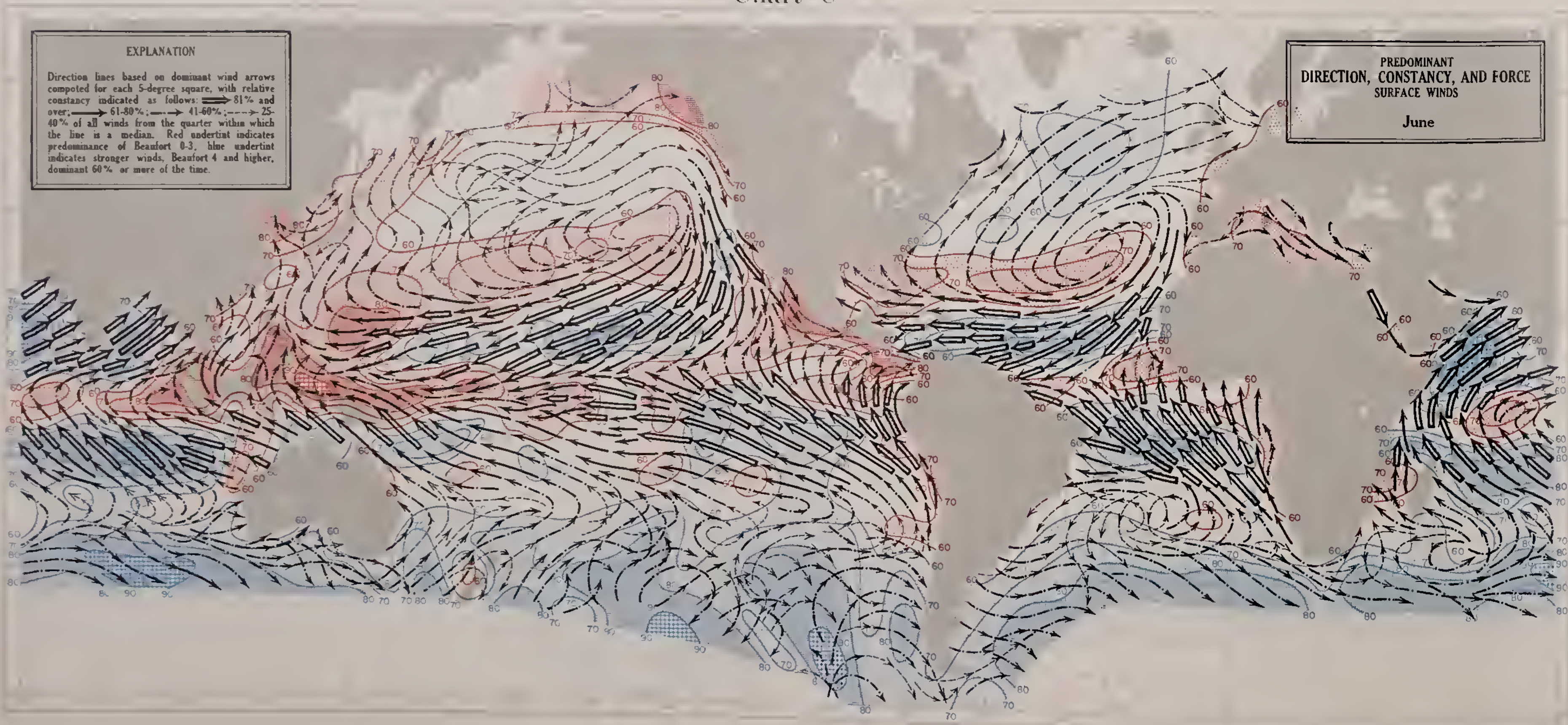

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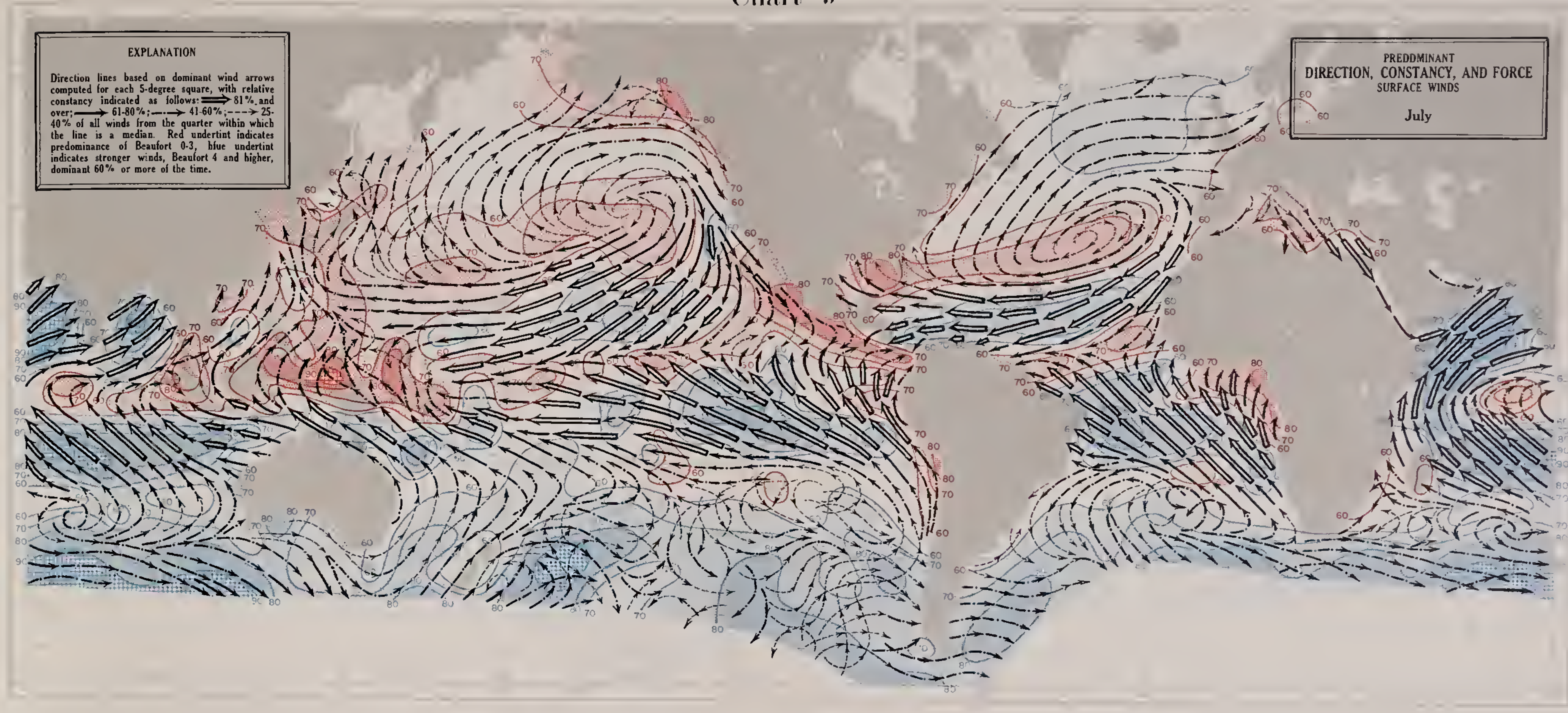

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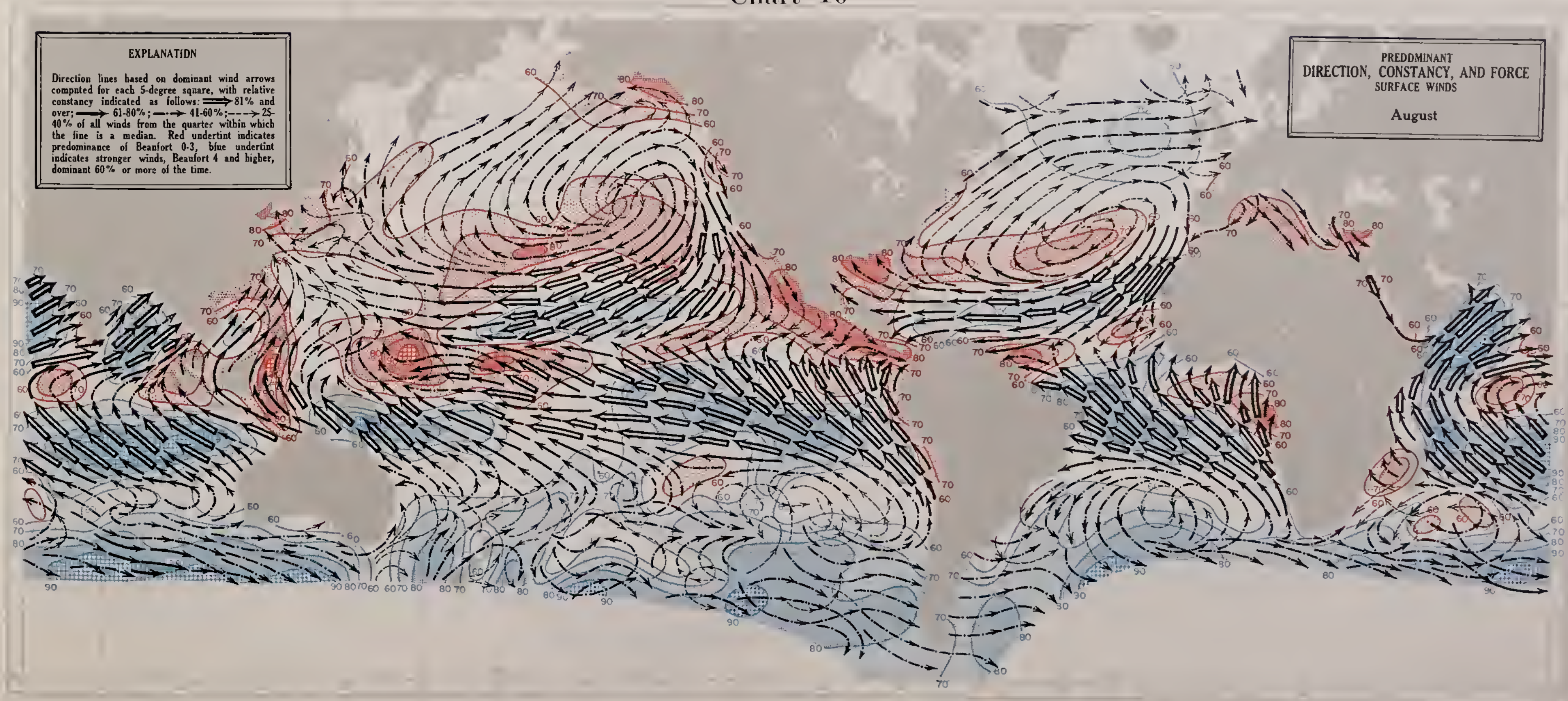

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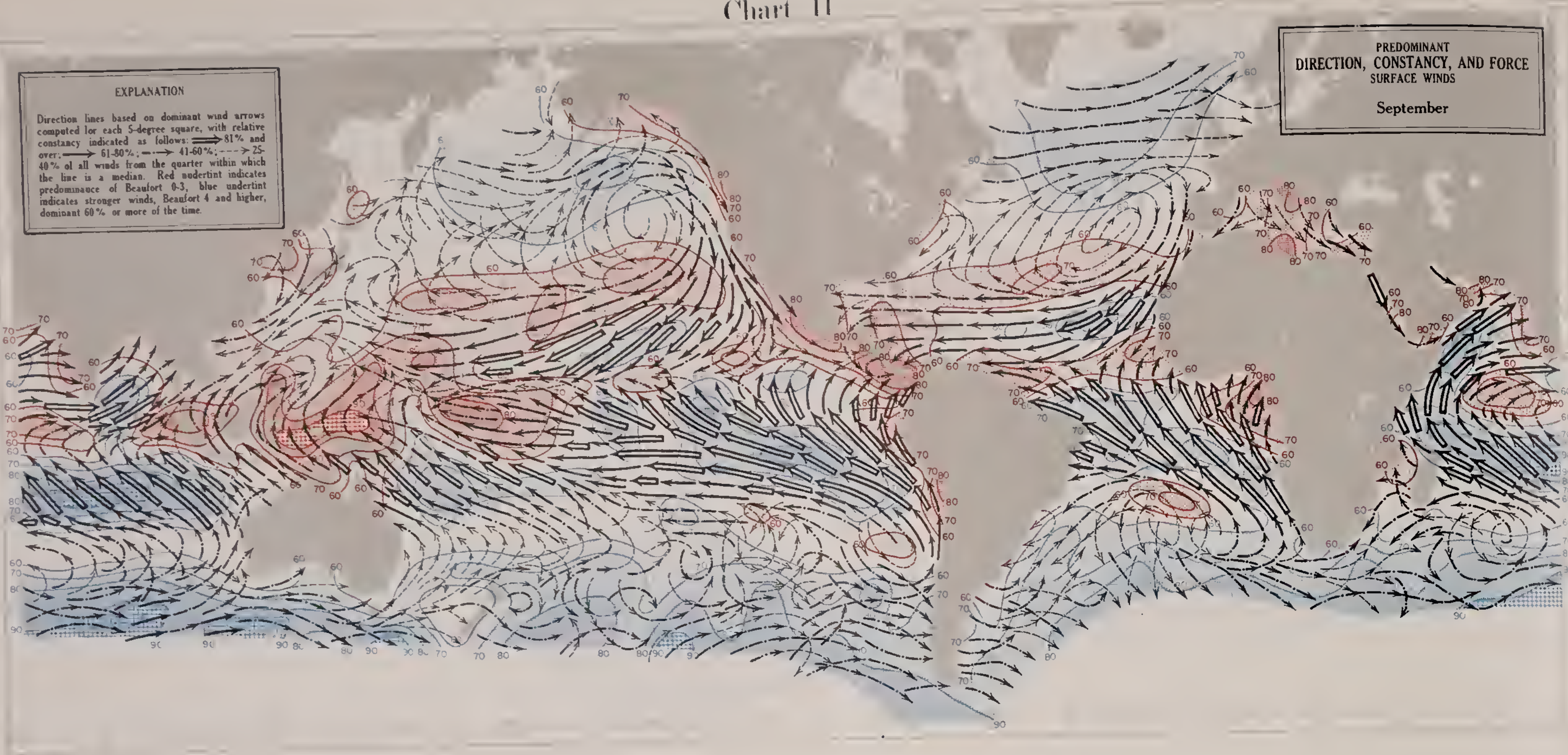

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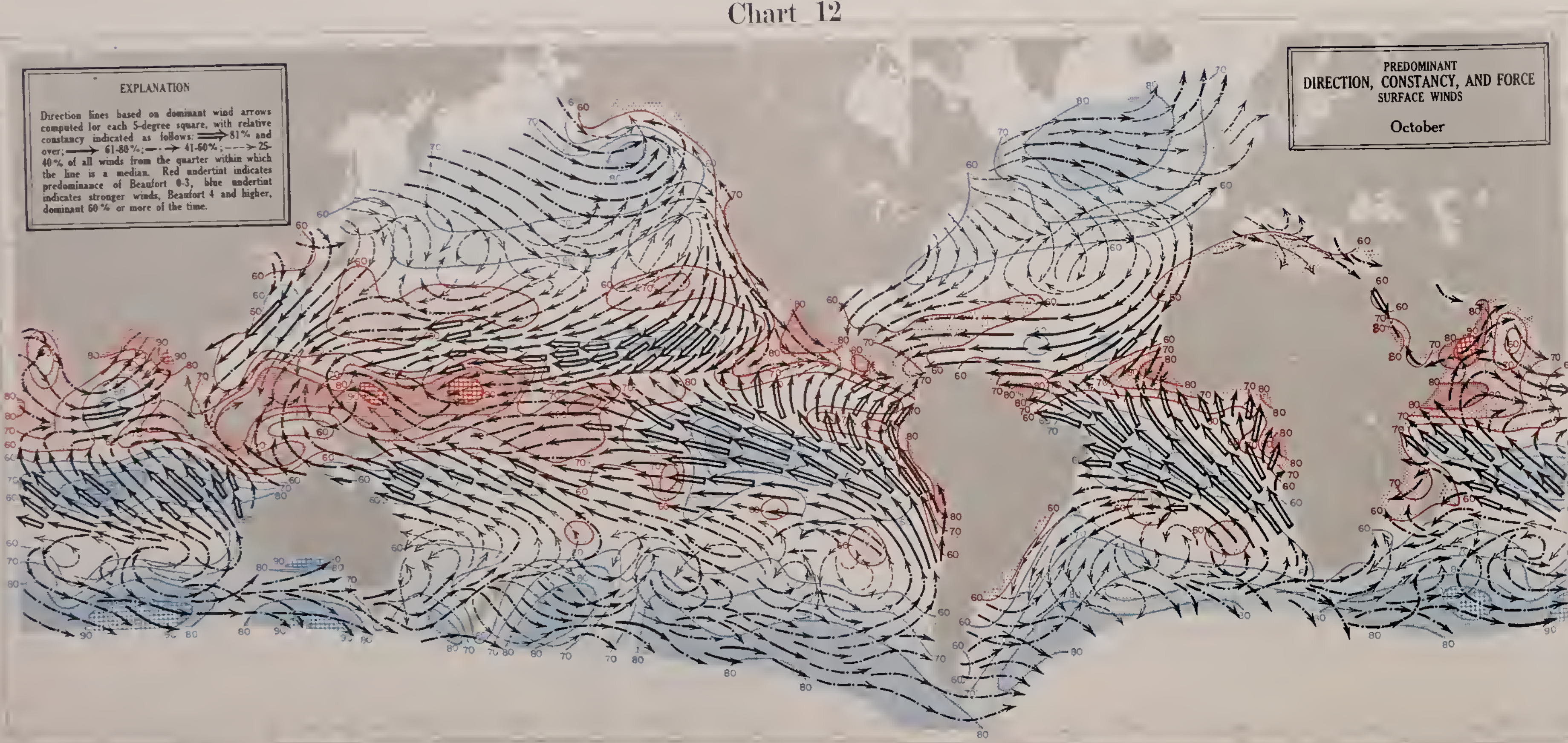

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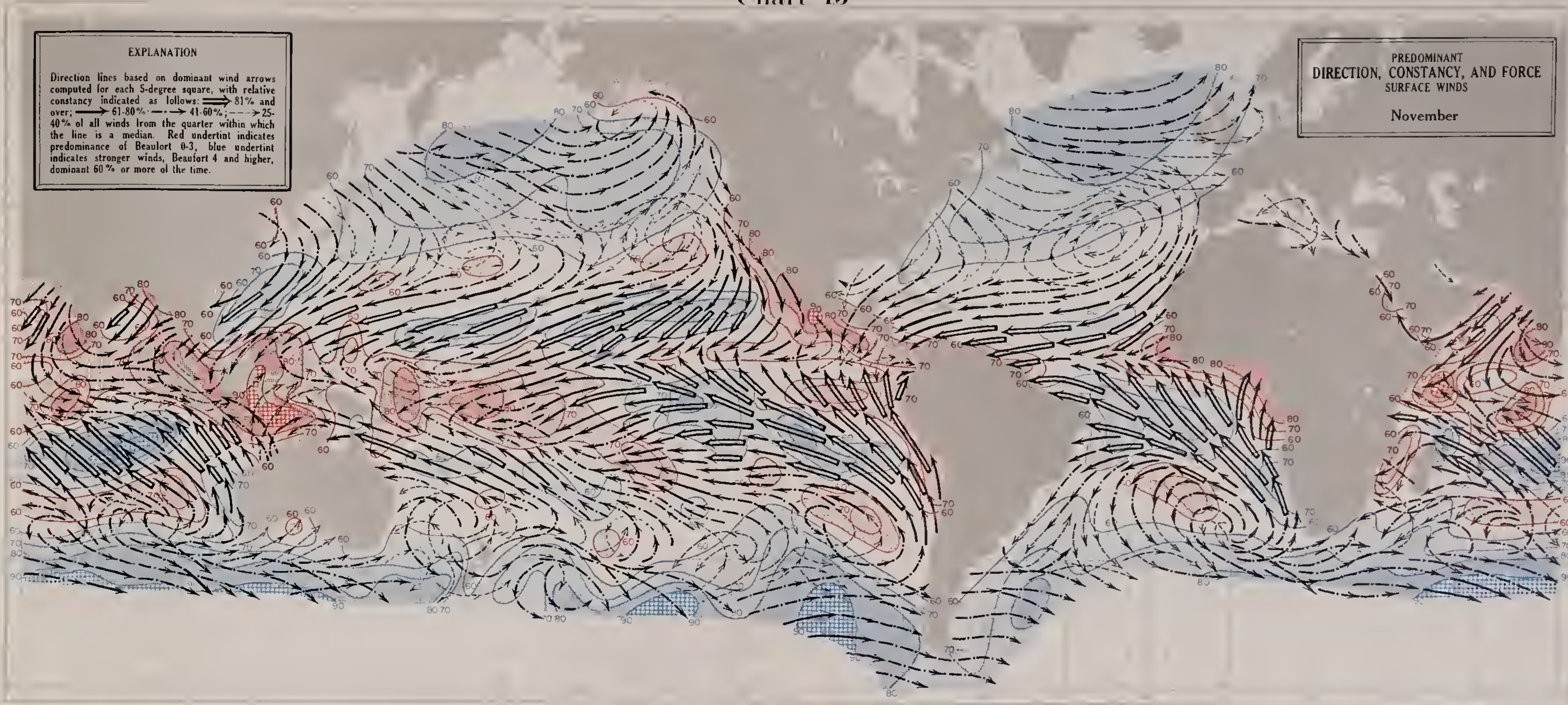

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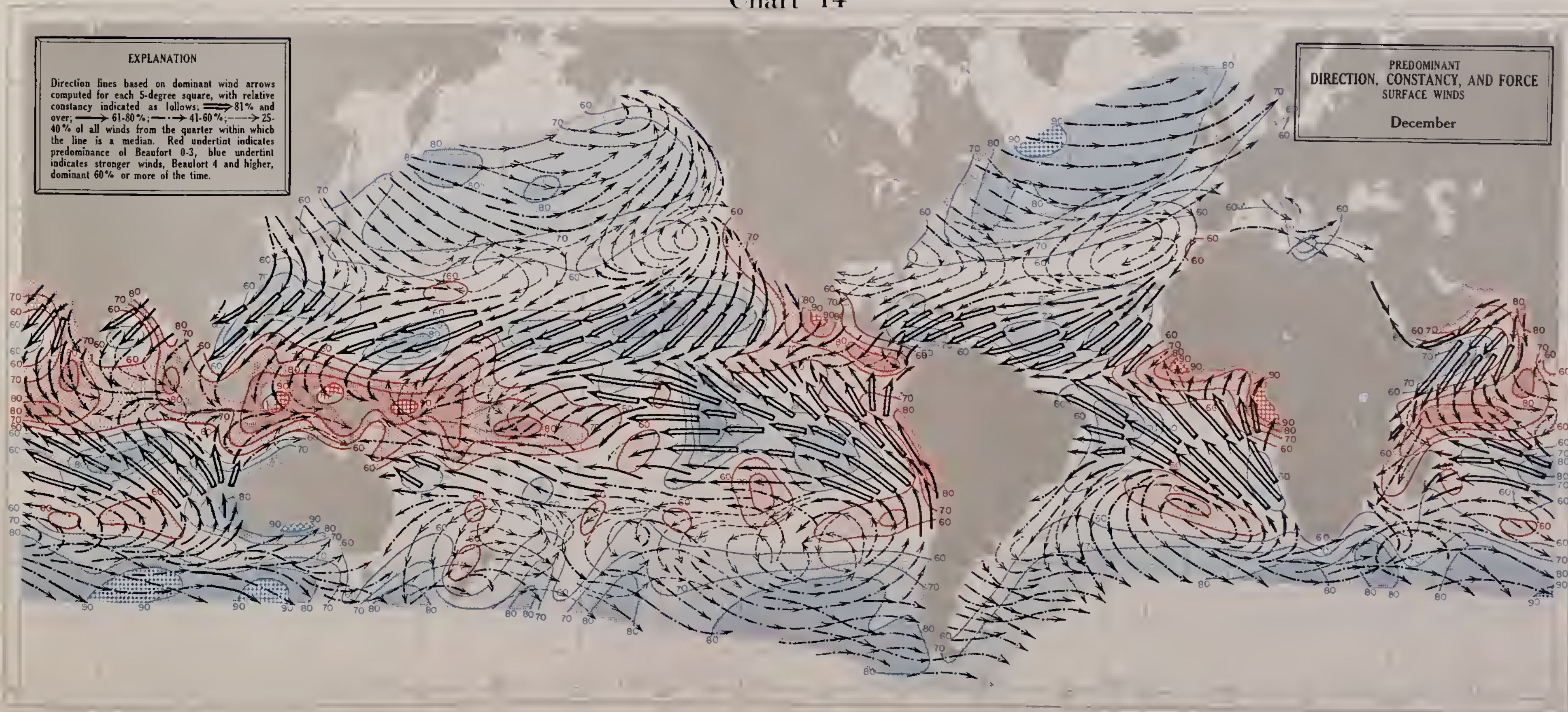

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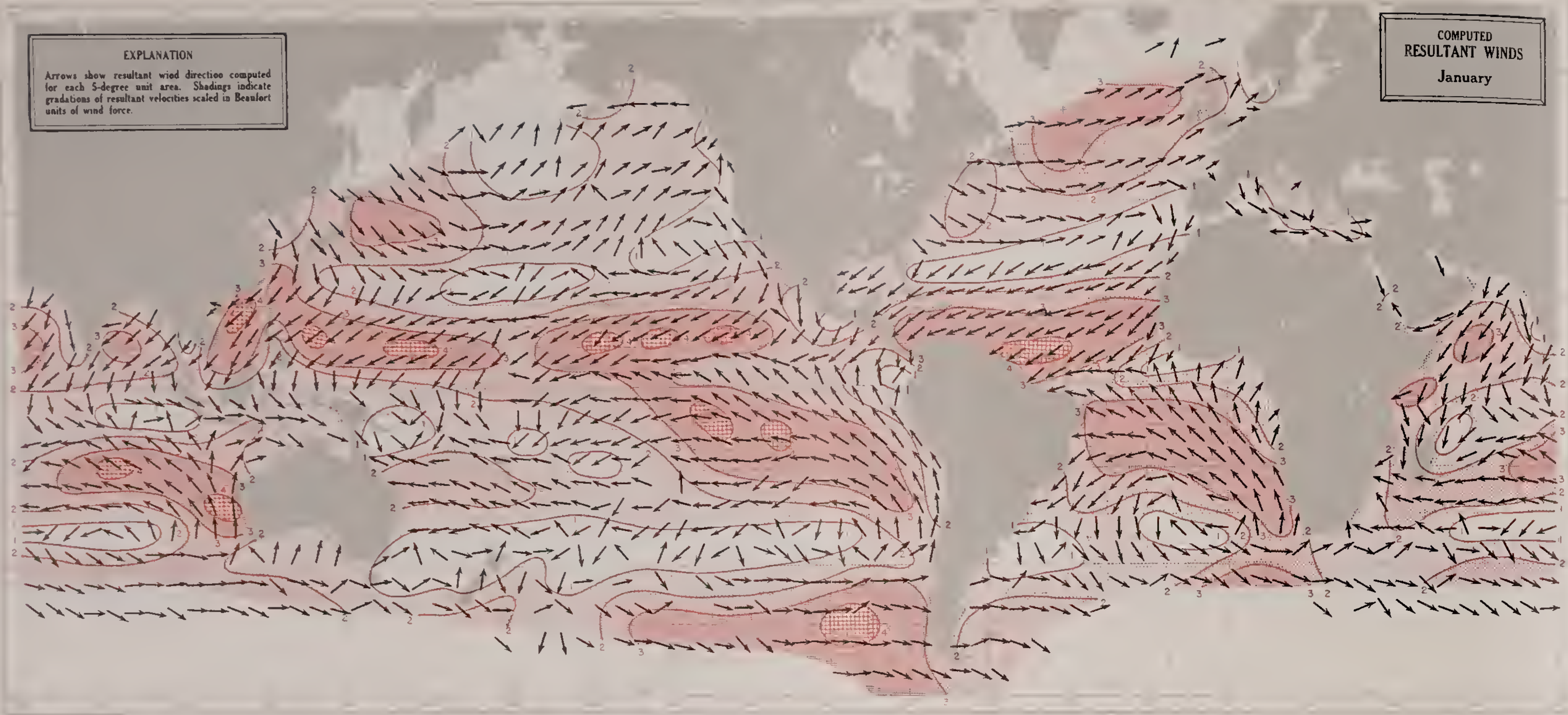

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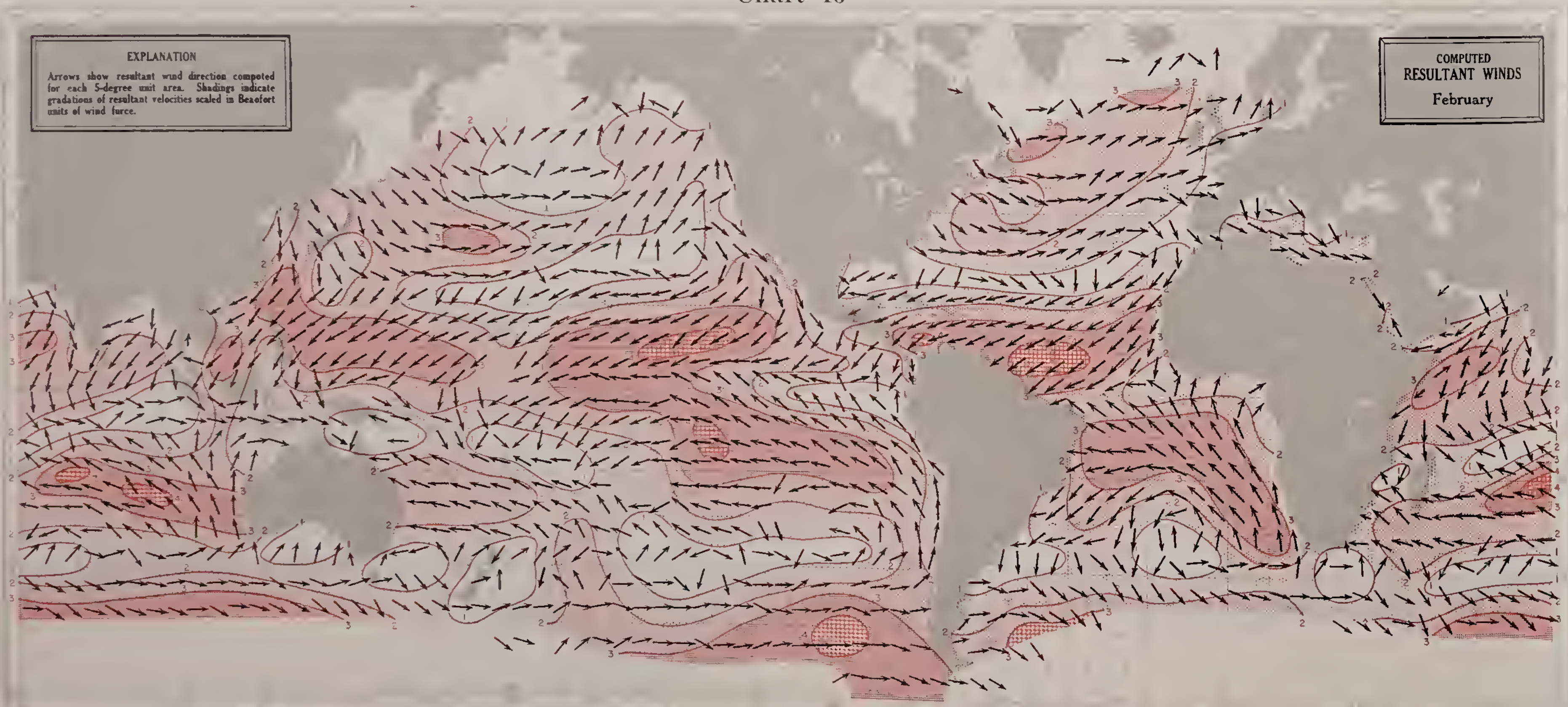

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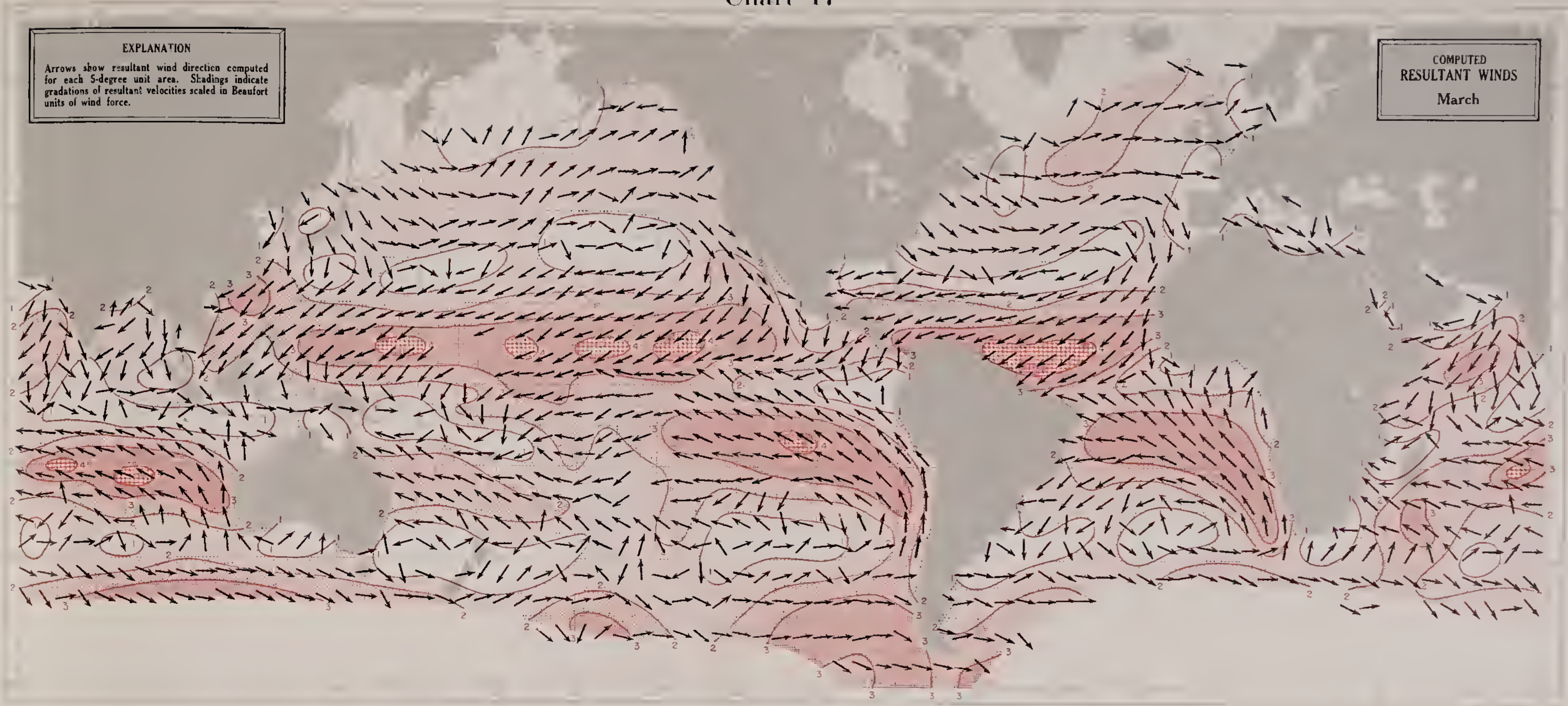

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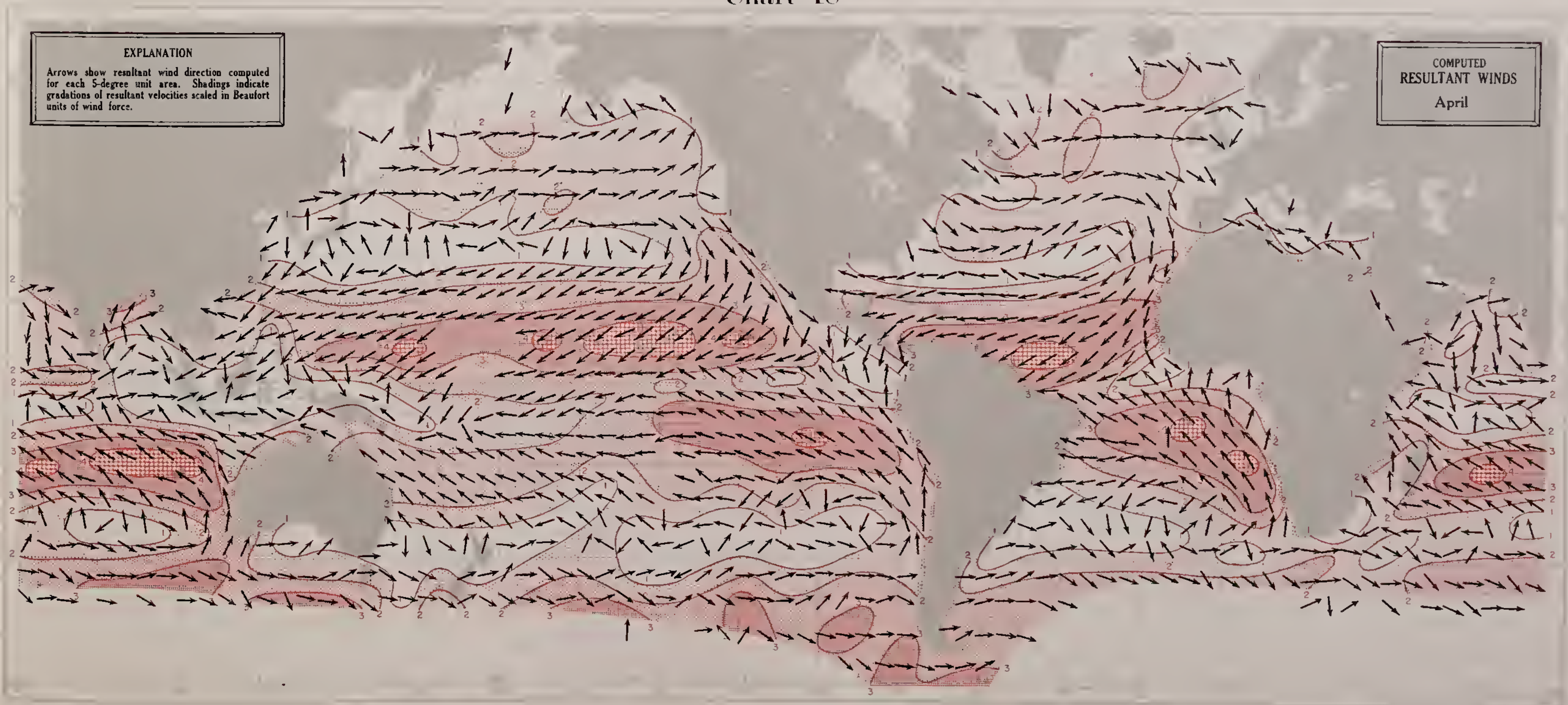

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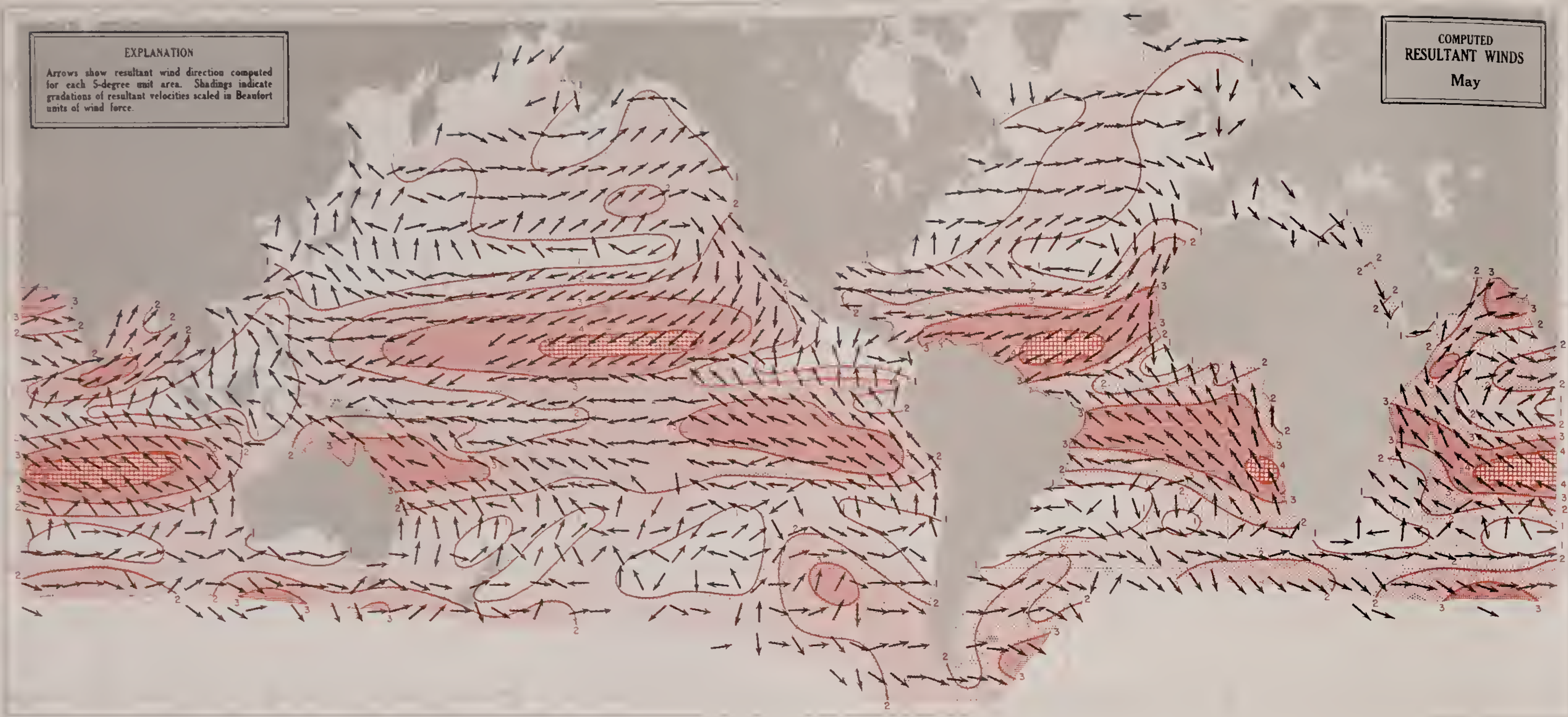

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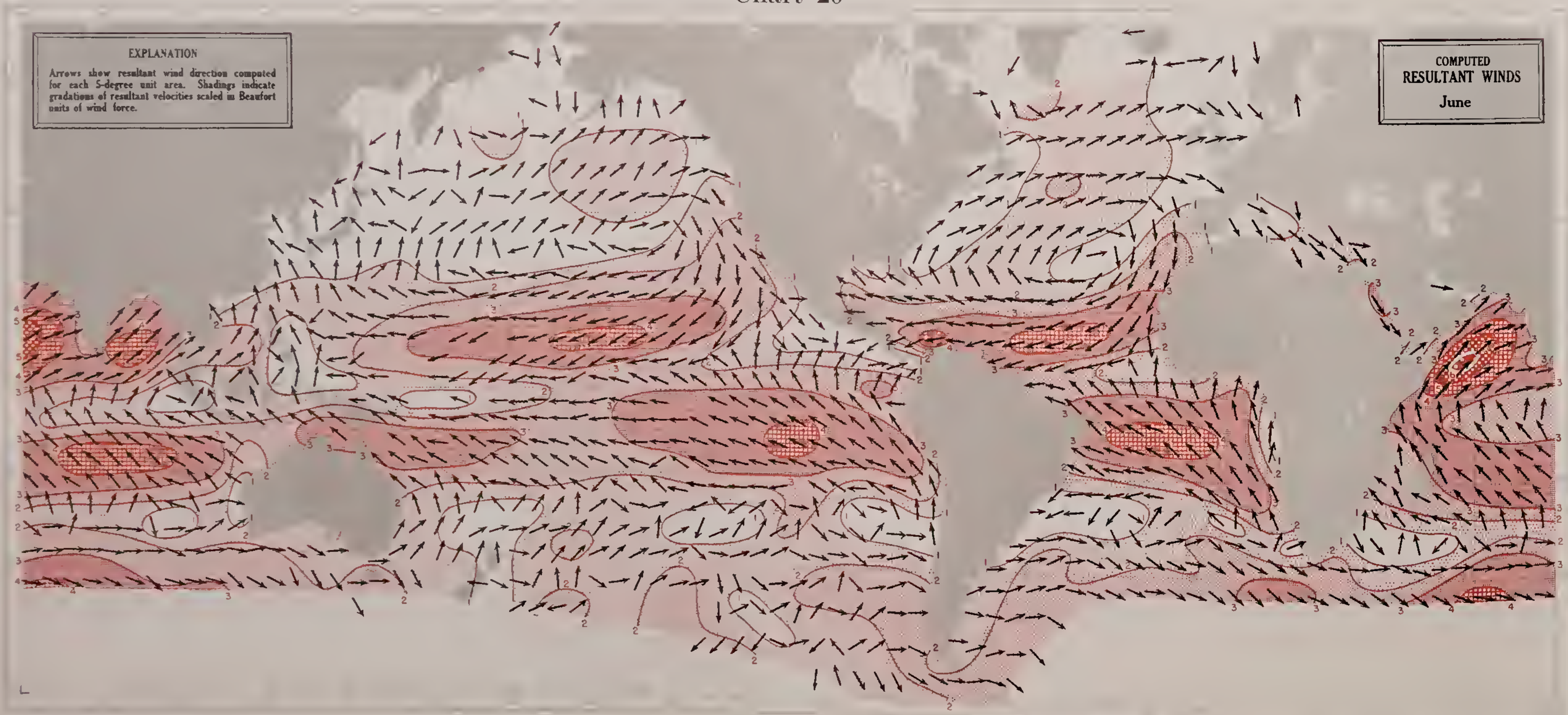

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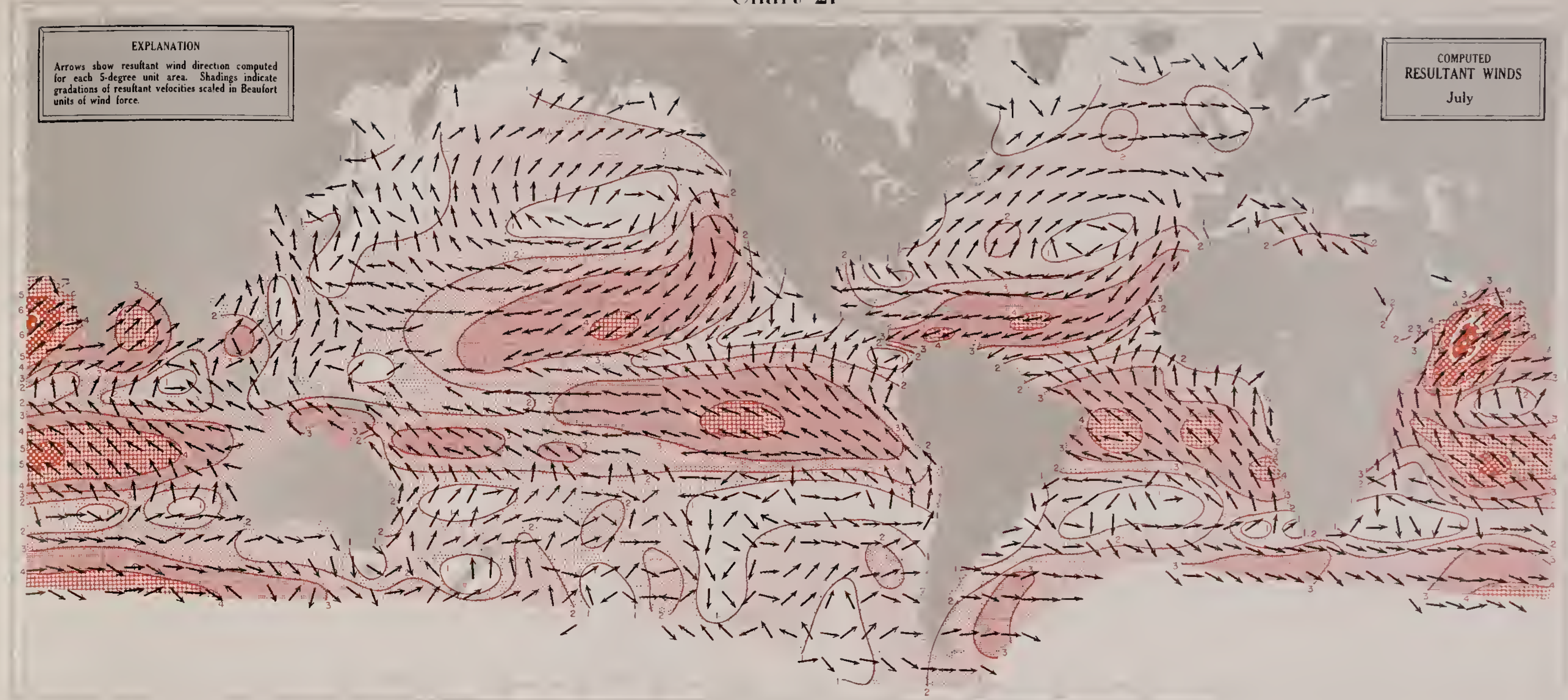

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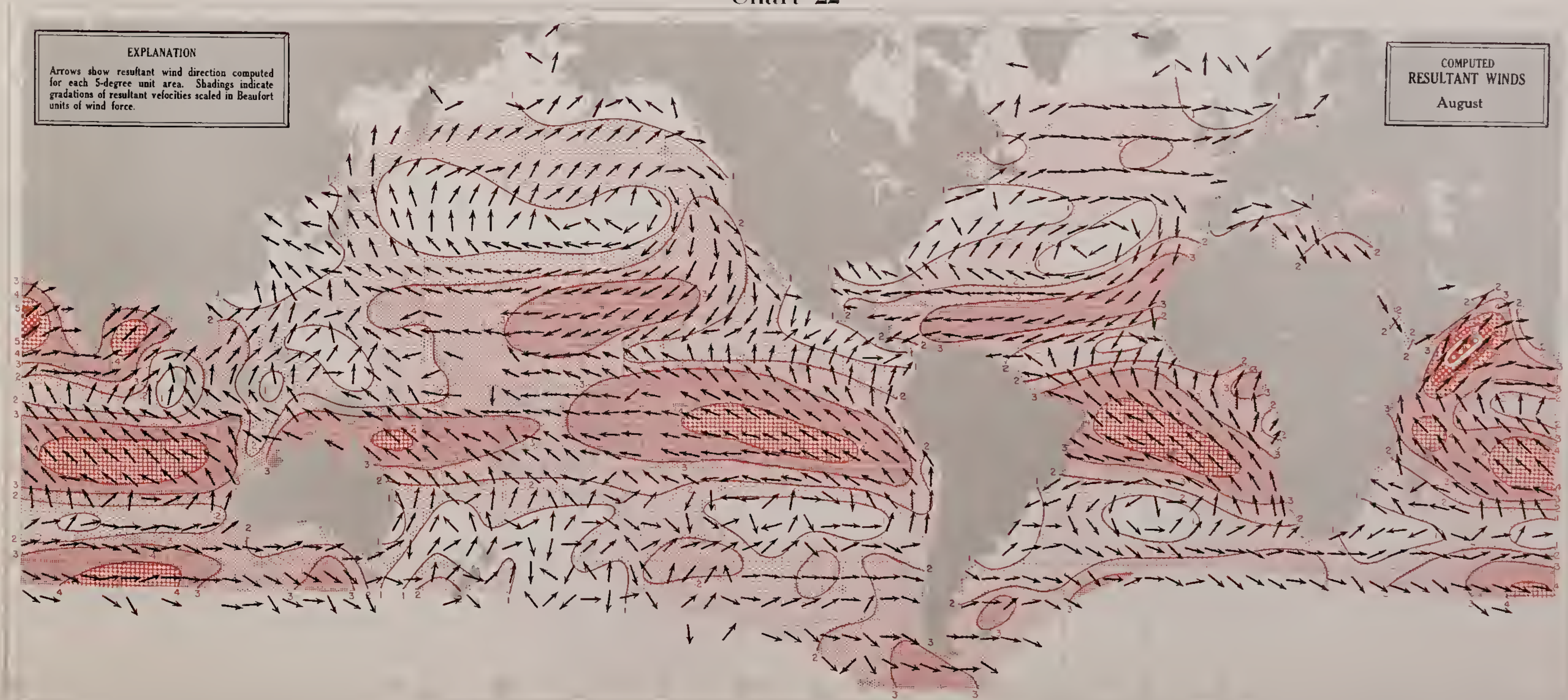

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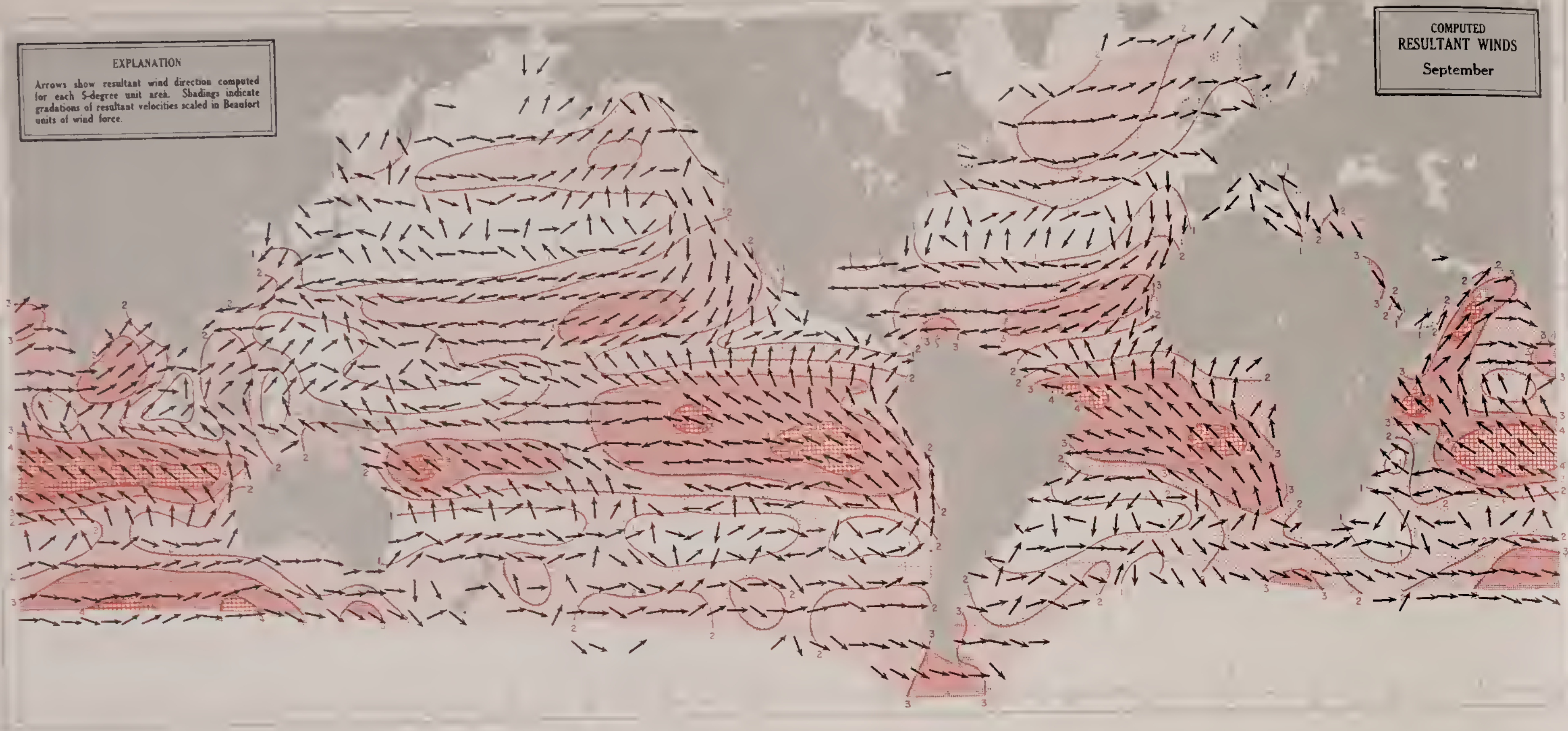

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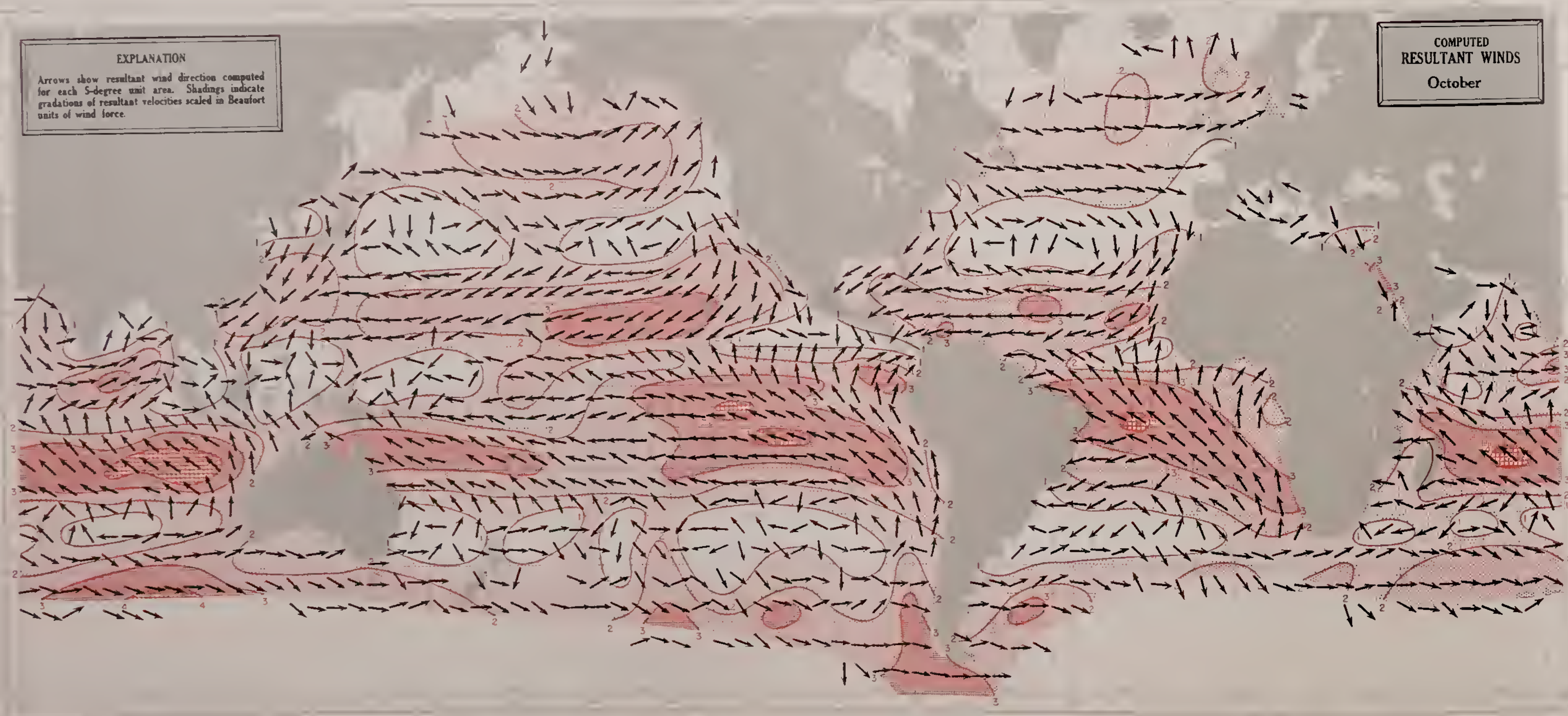

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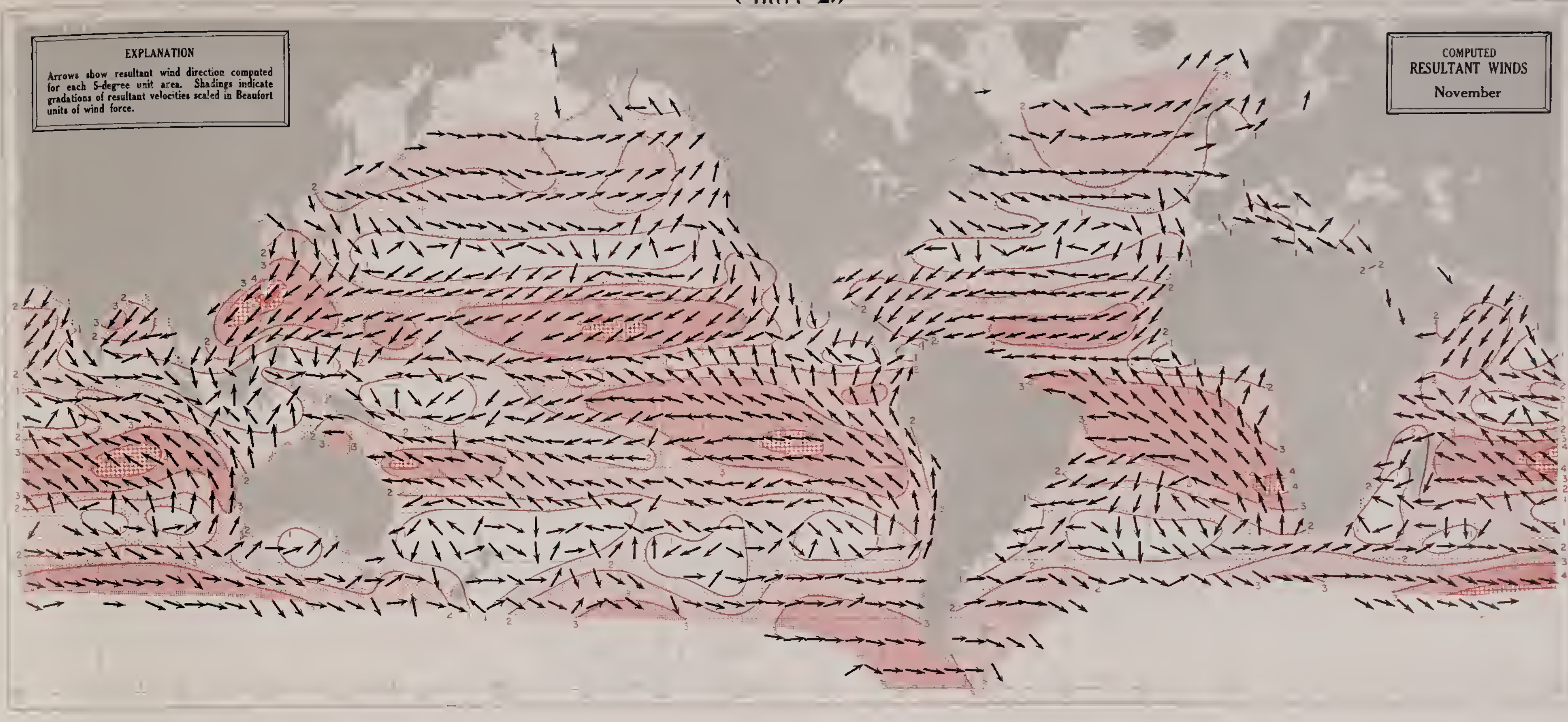

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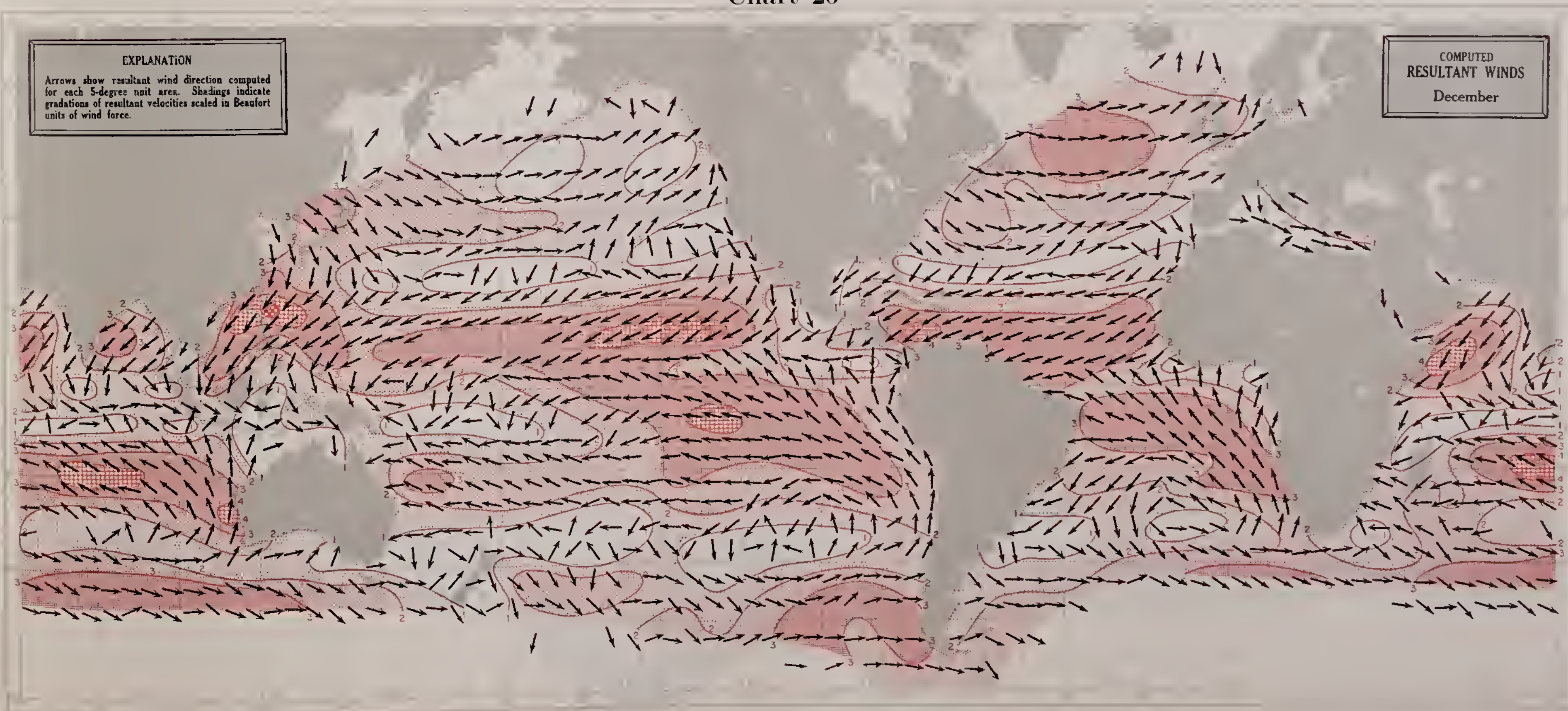
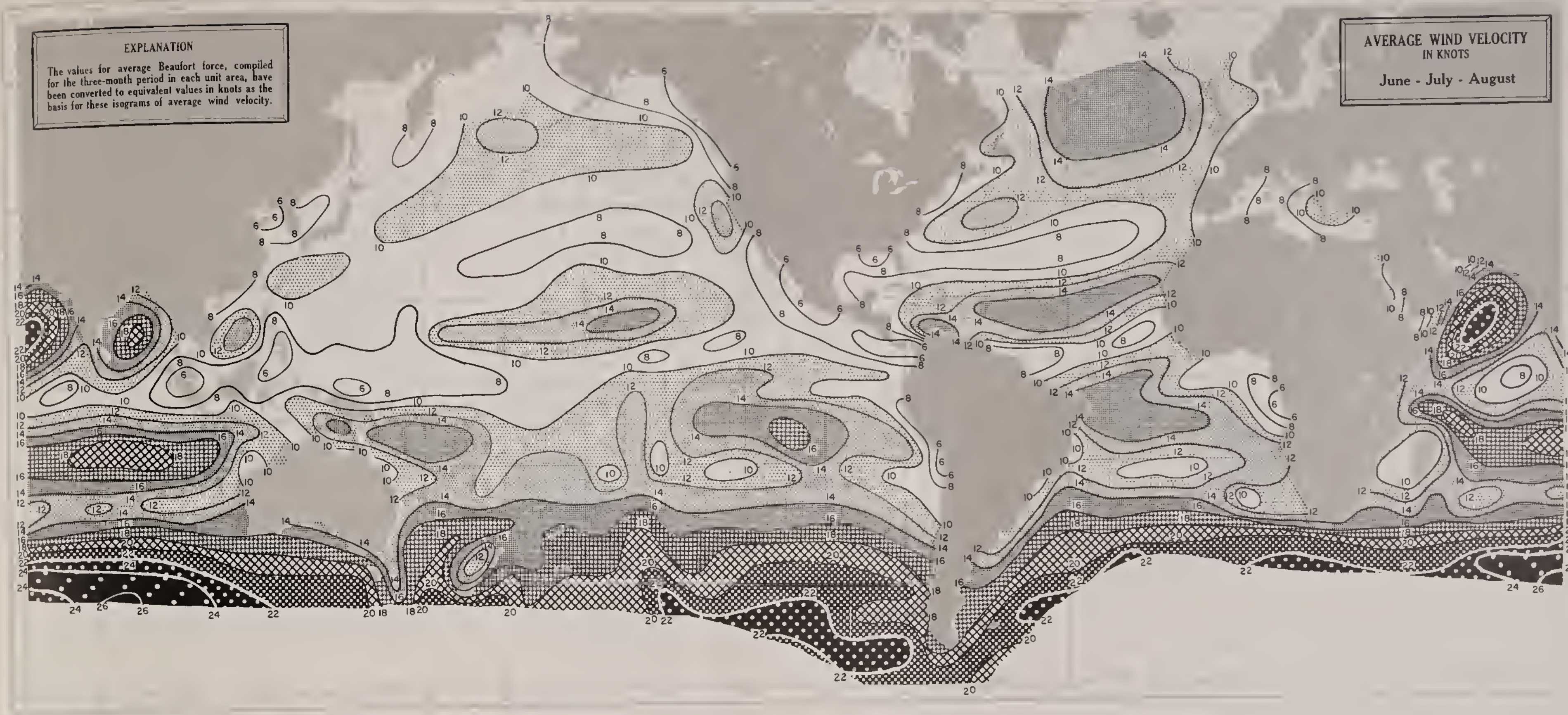


Chart 27

Chart 28

Chart 29



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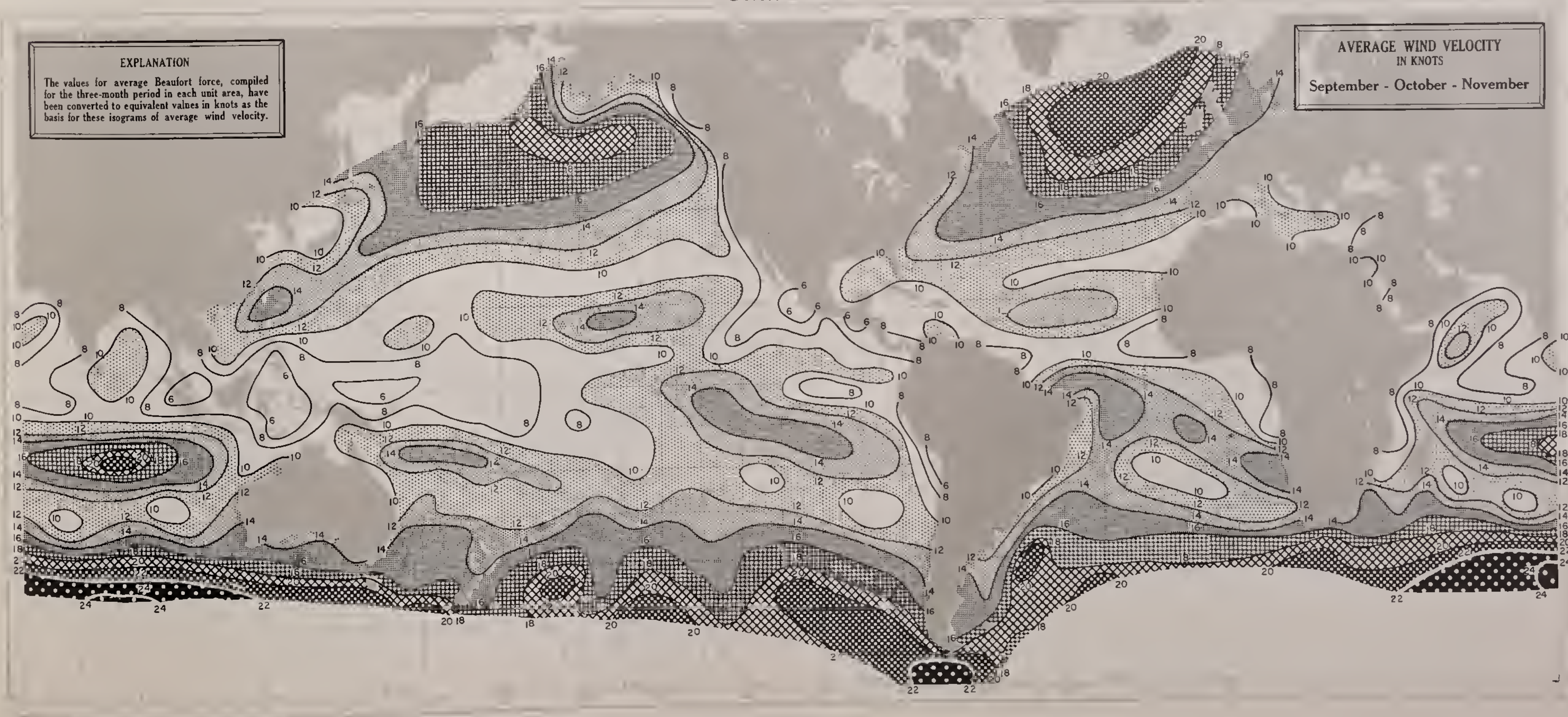


Chart 31

Chart 32

Chart 33

Chart 34

Chart 35

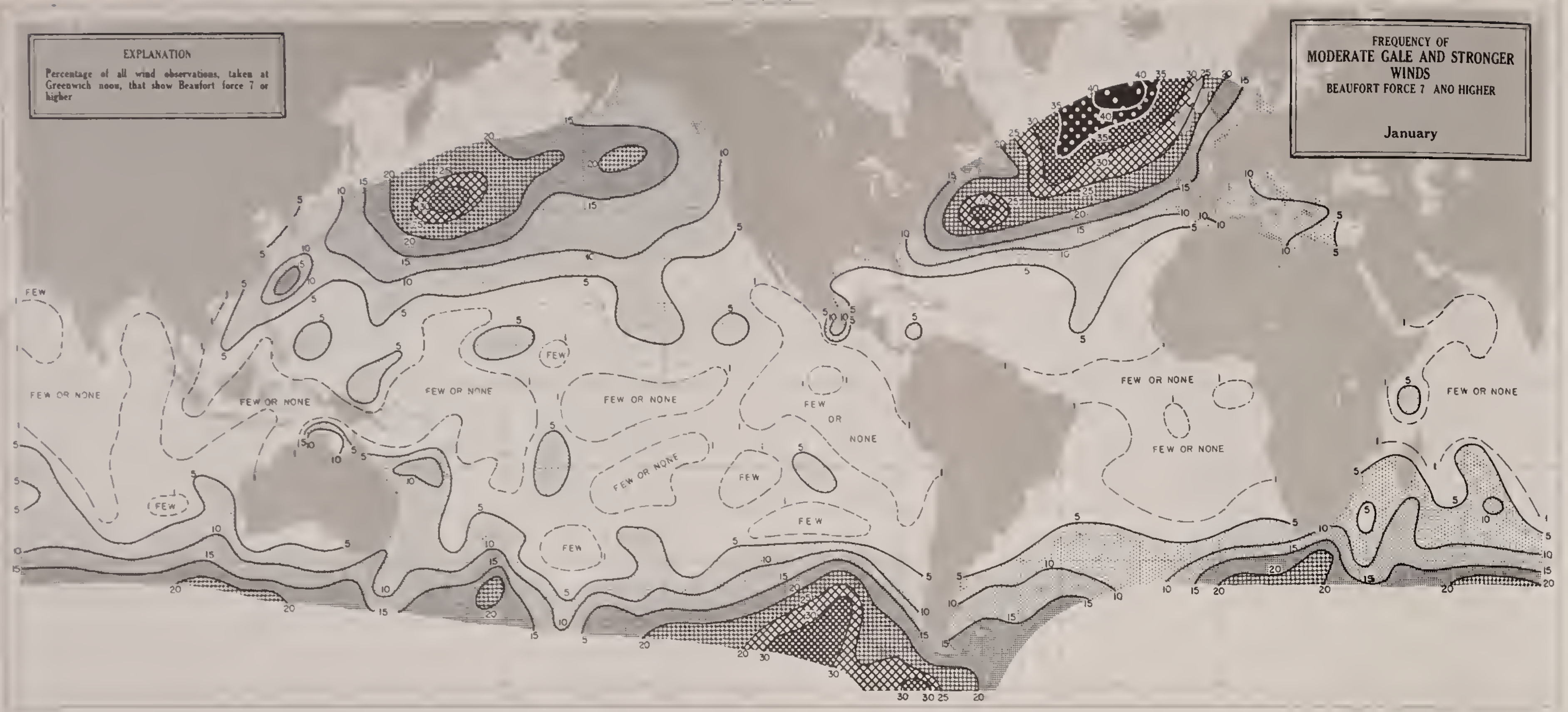


Chart 36

Chart 37

Chart 38

Chart 39

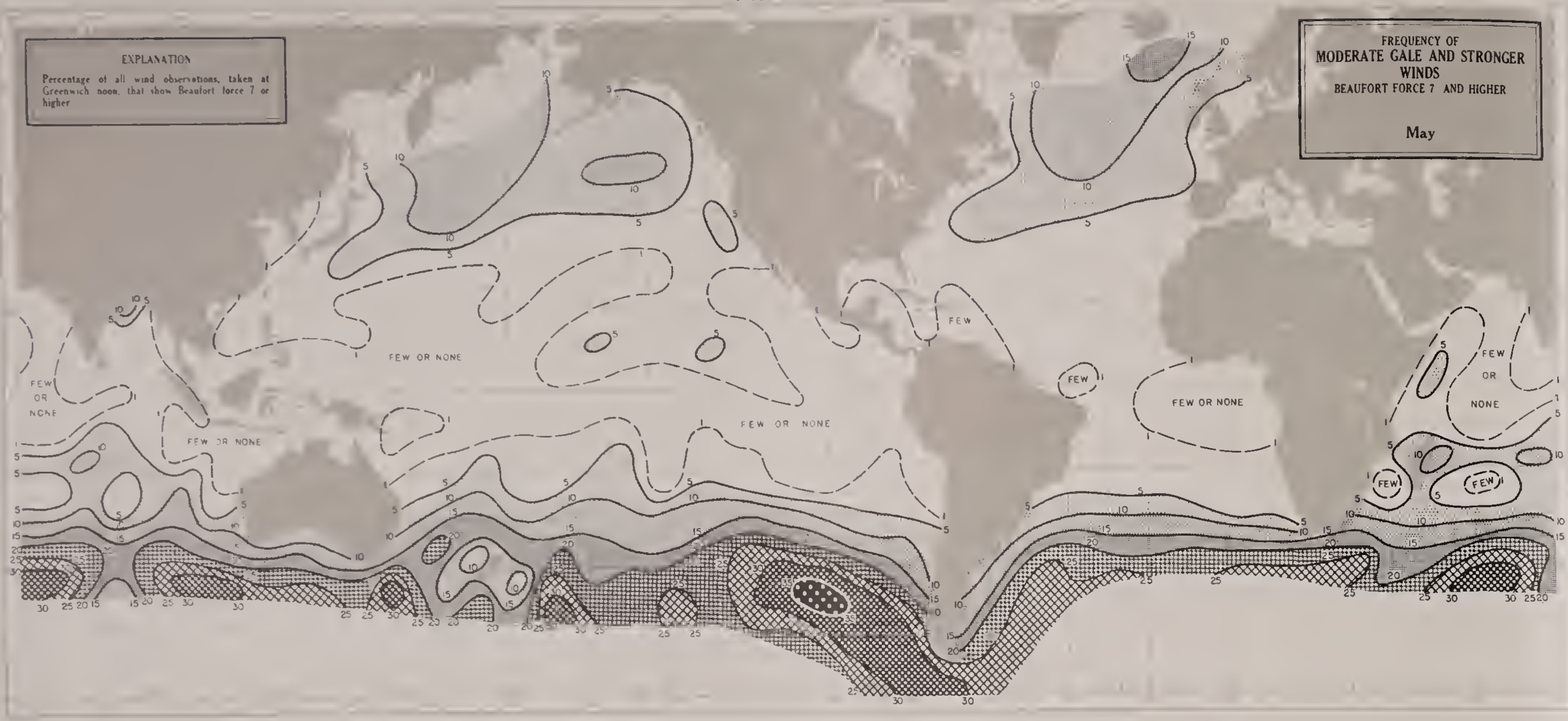


Chart 40

Chart 41

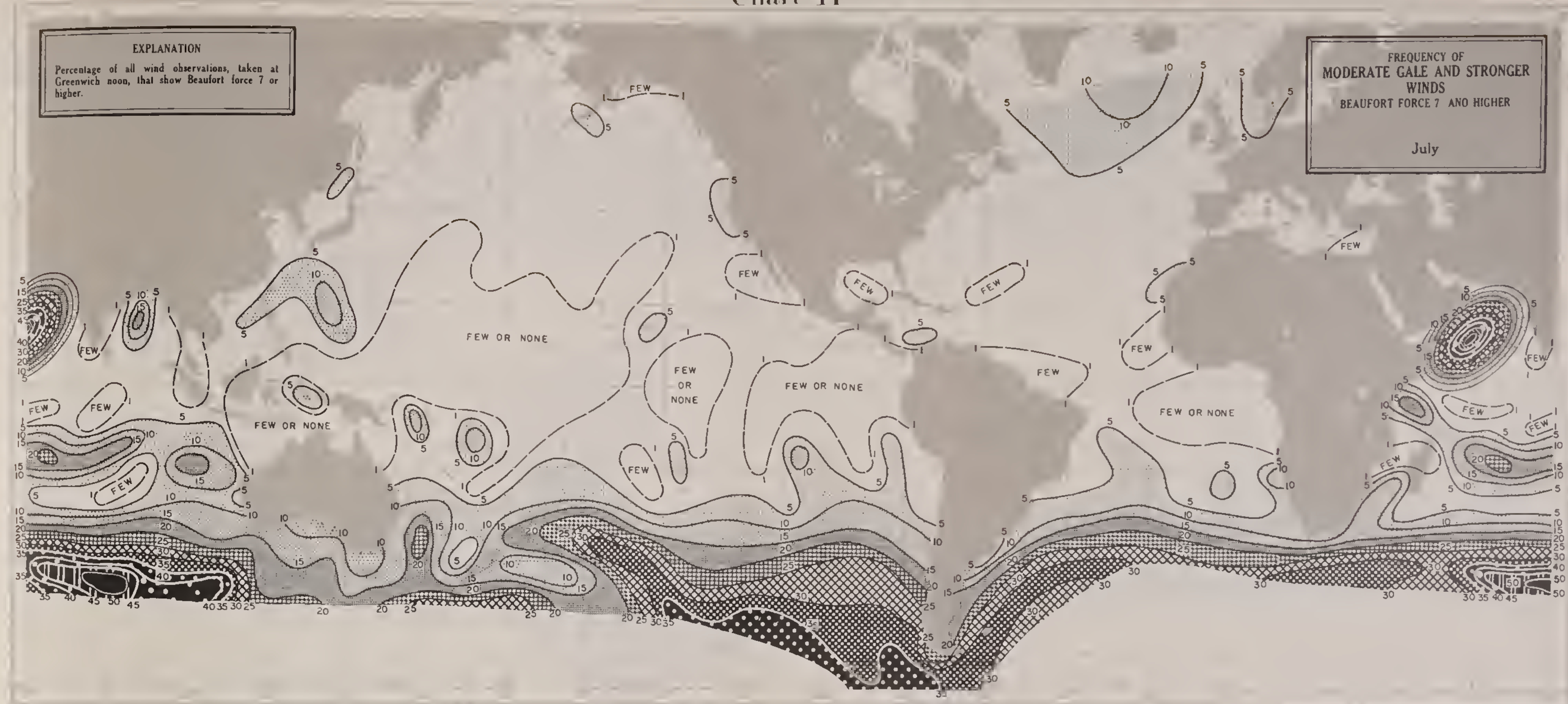


Chart 42

Chart 43

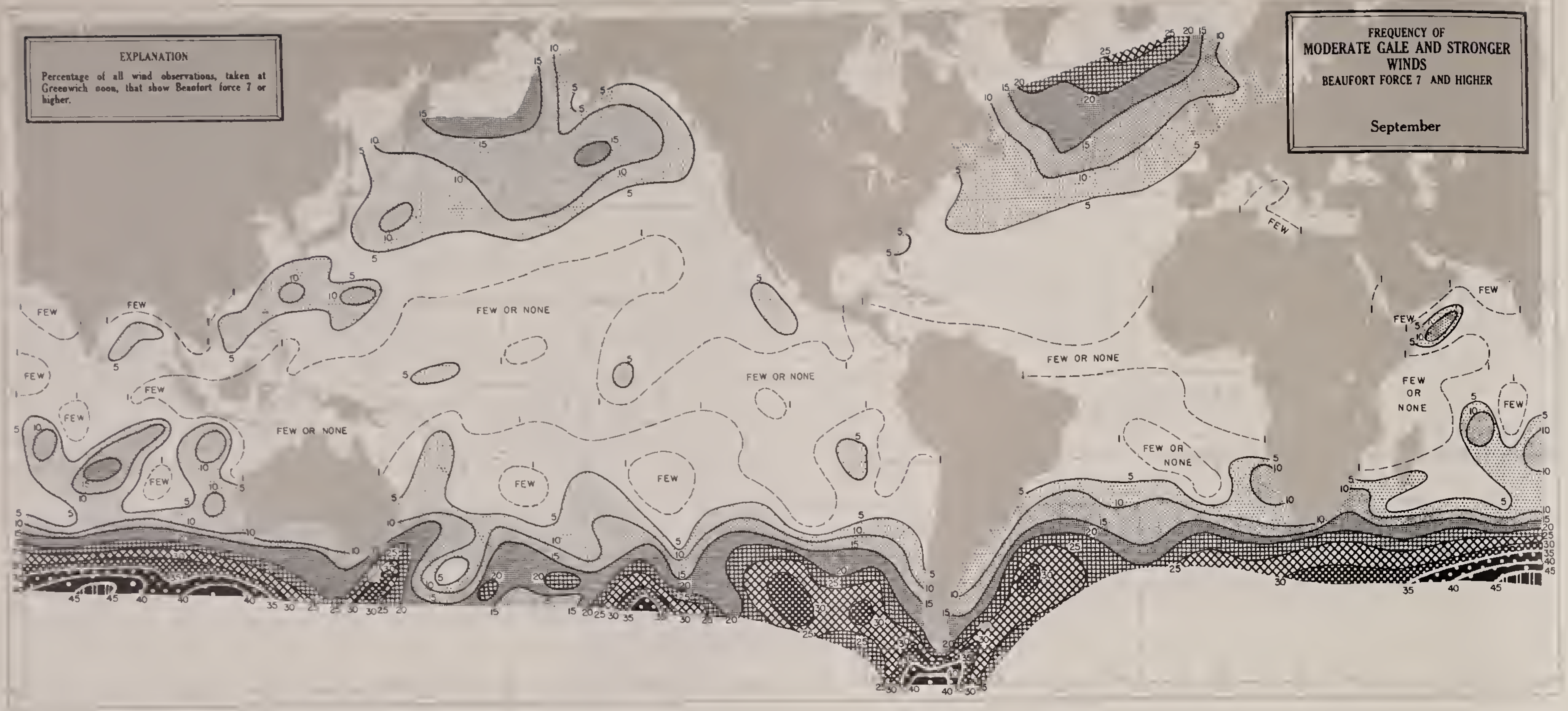


Chart 44

Chart 45

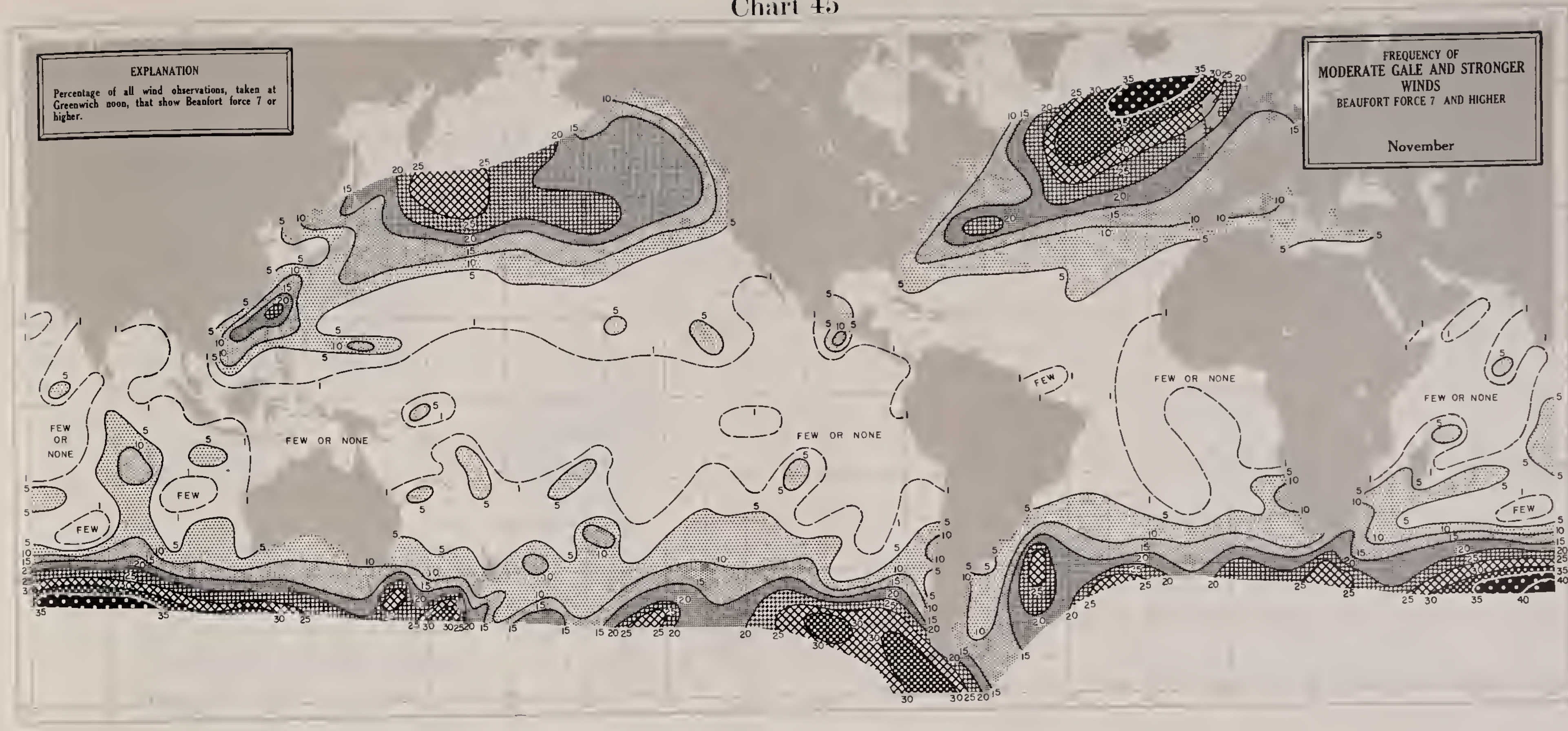


Chart 46

Chart 47

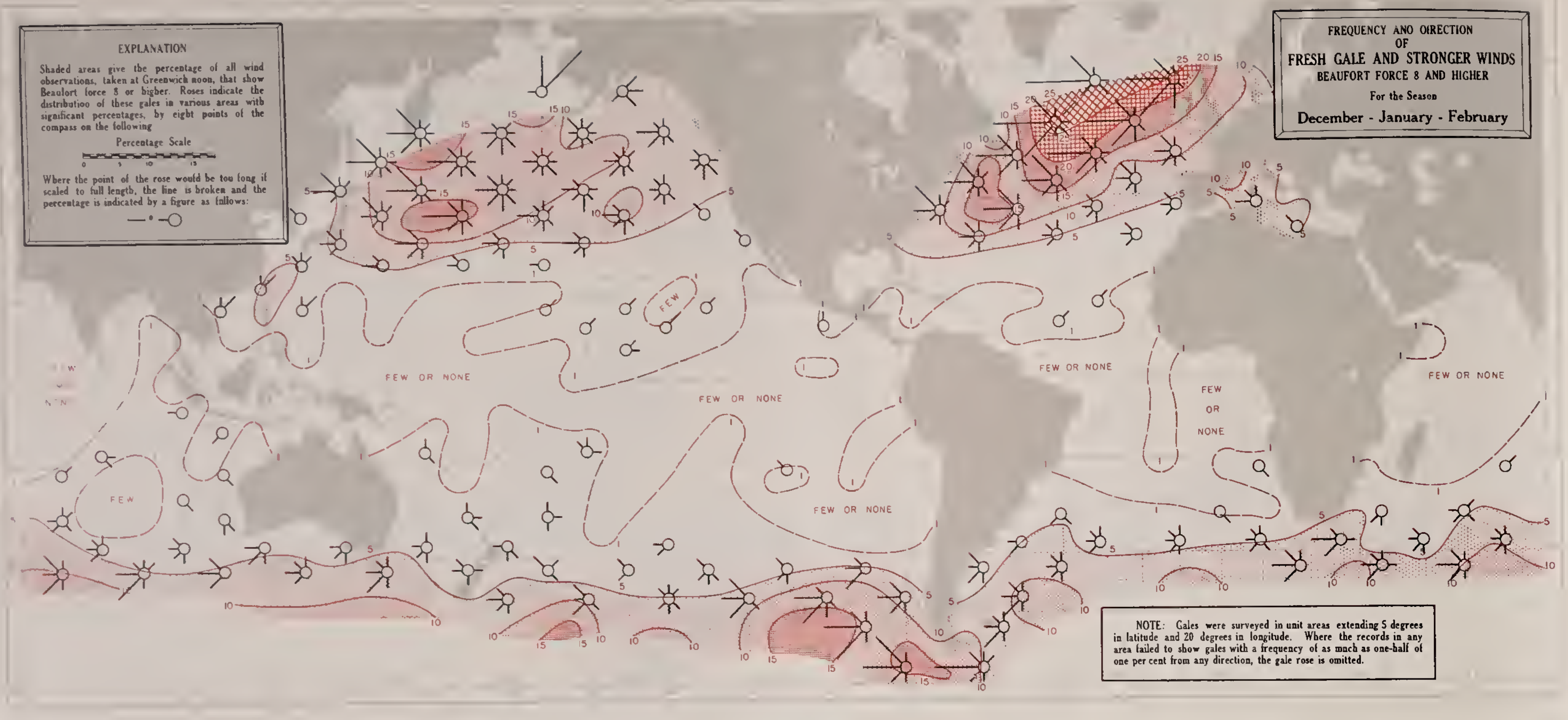
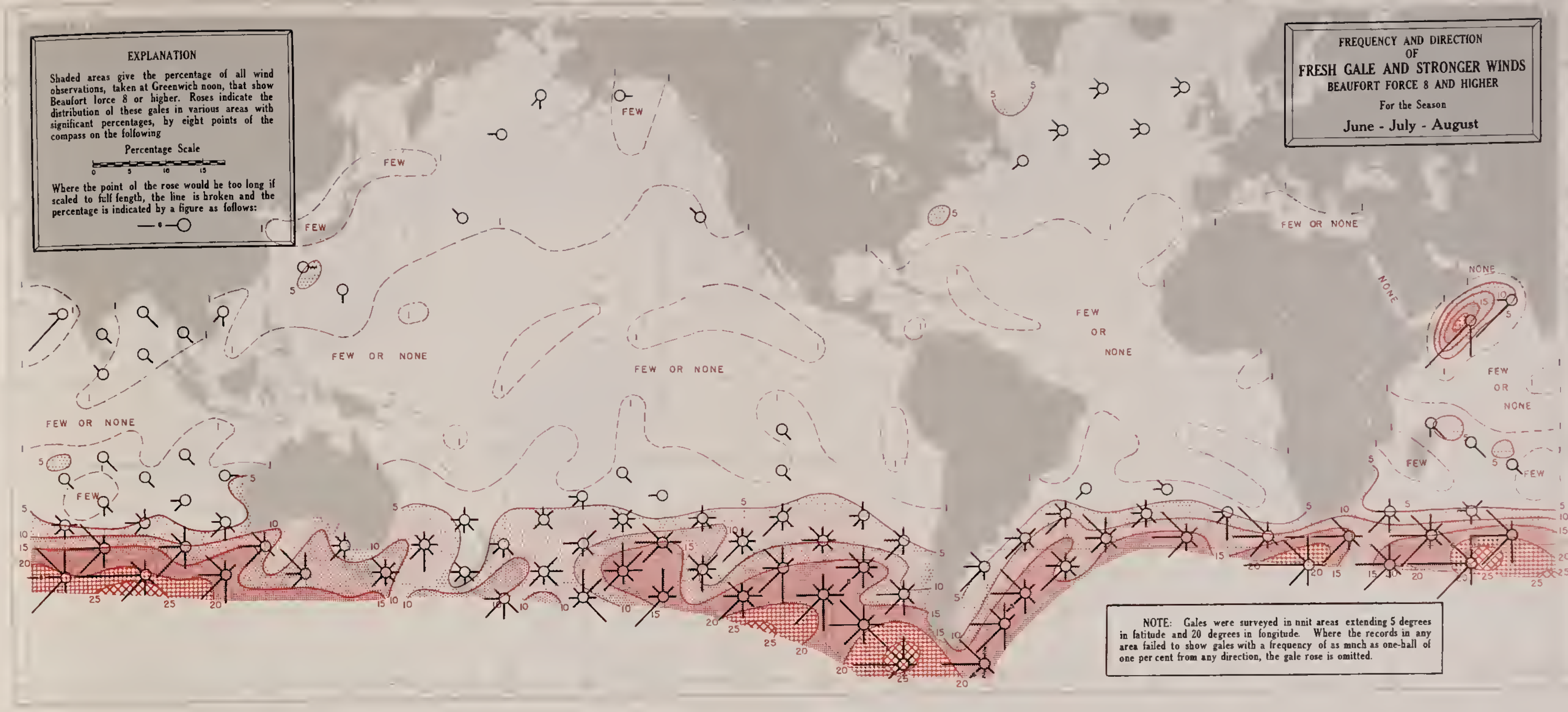


Chart 48

Chart 49



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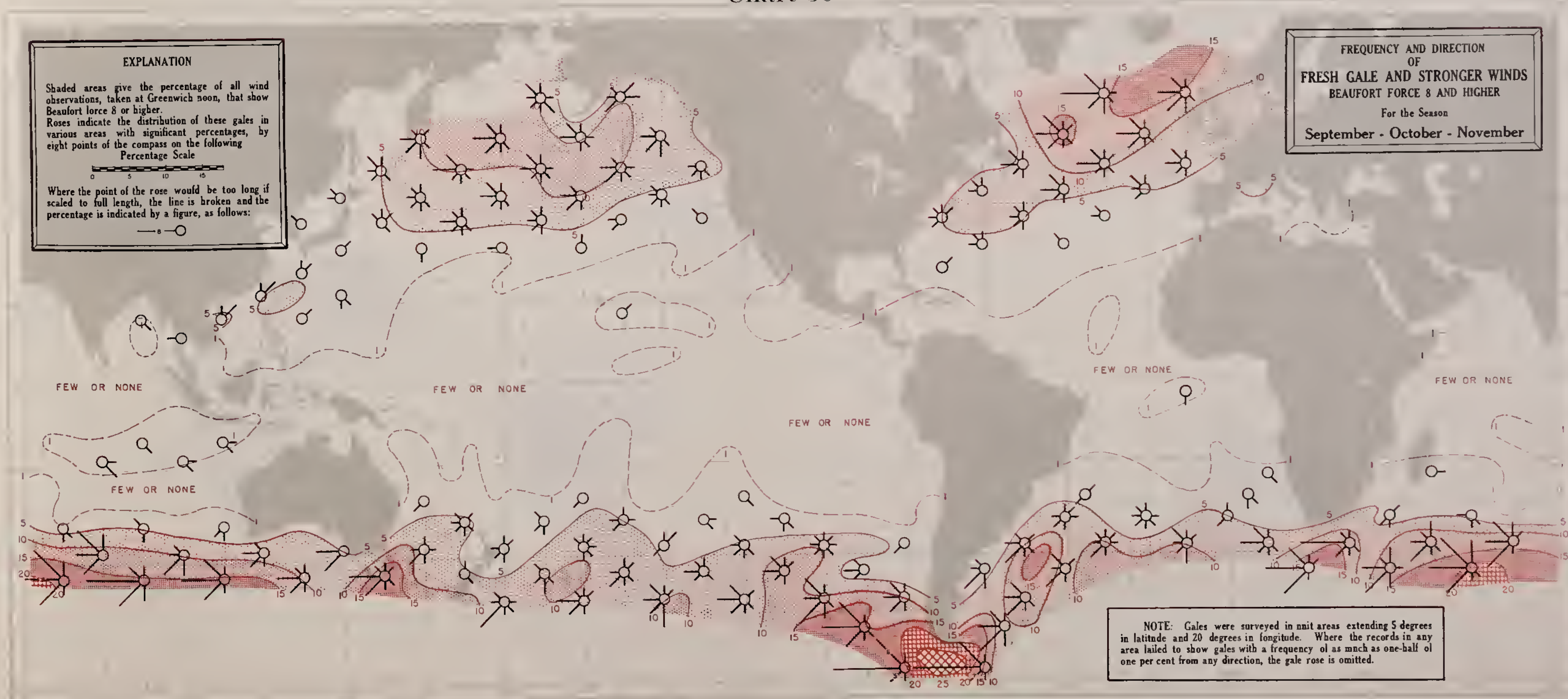

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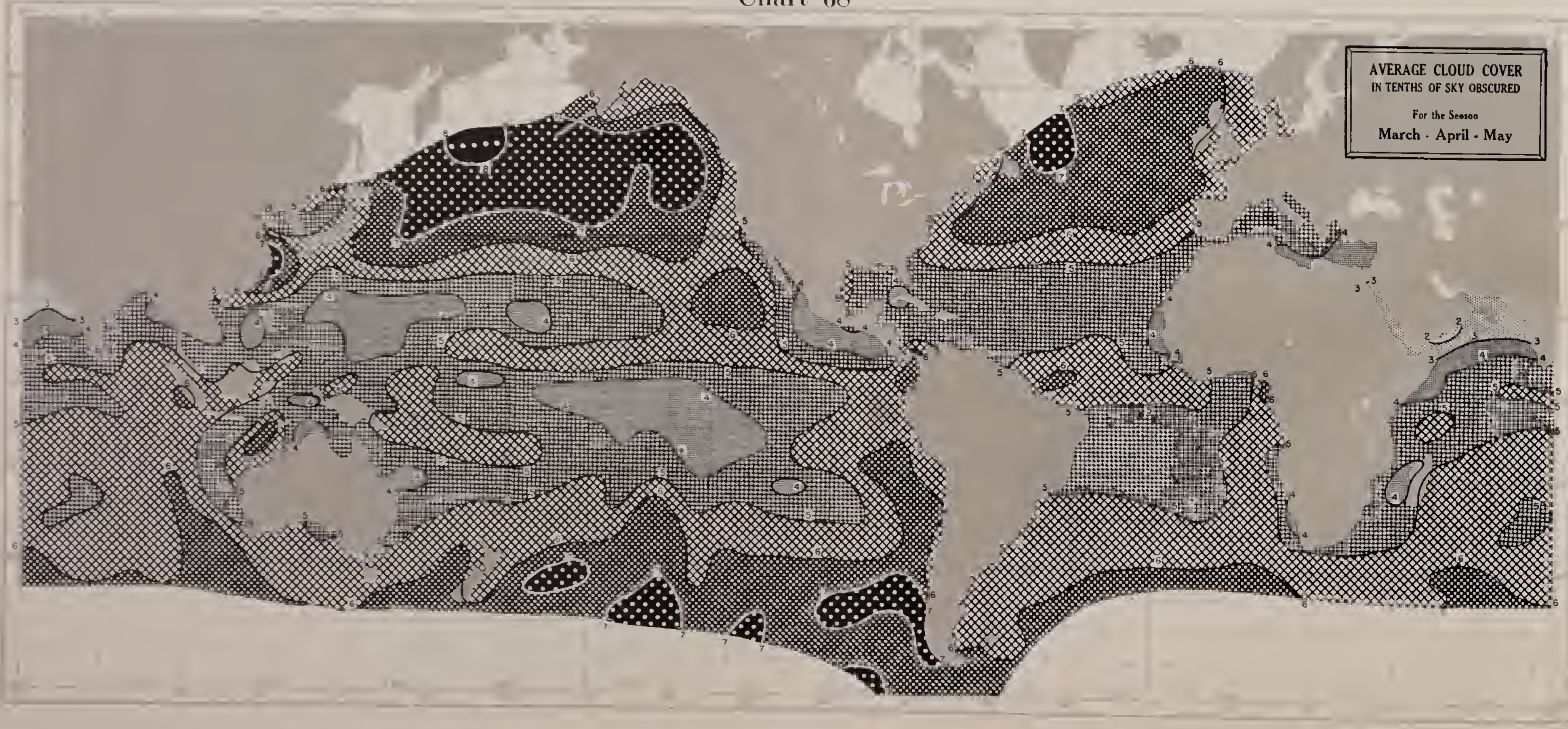

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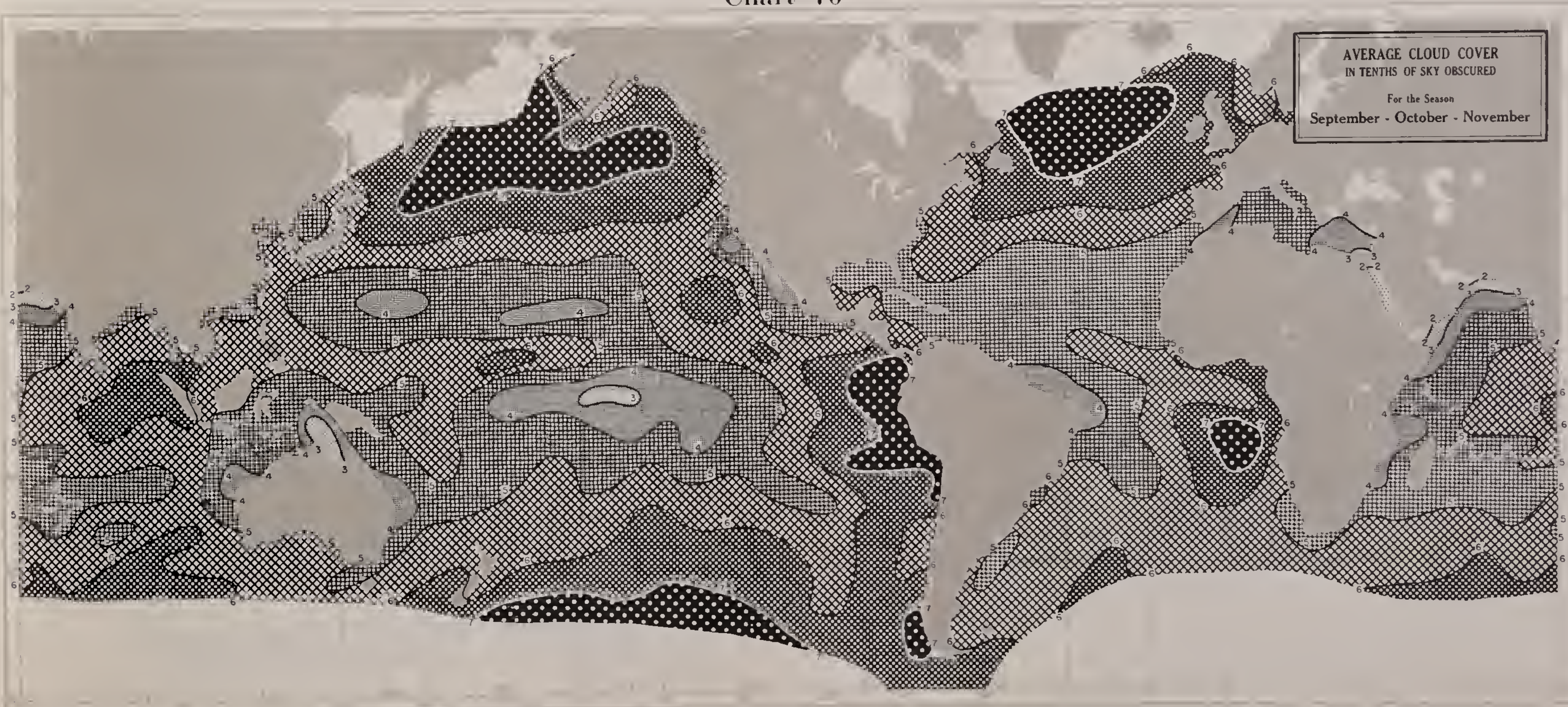

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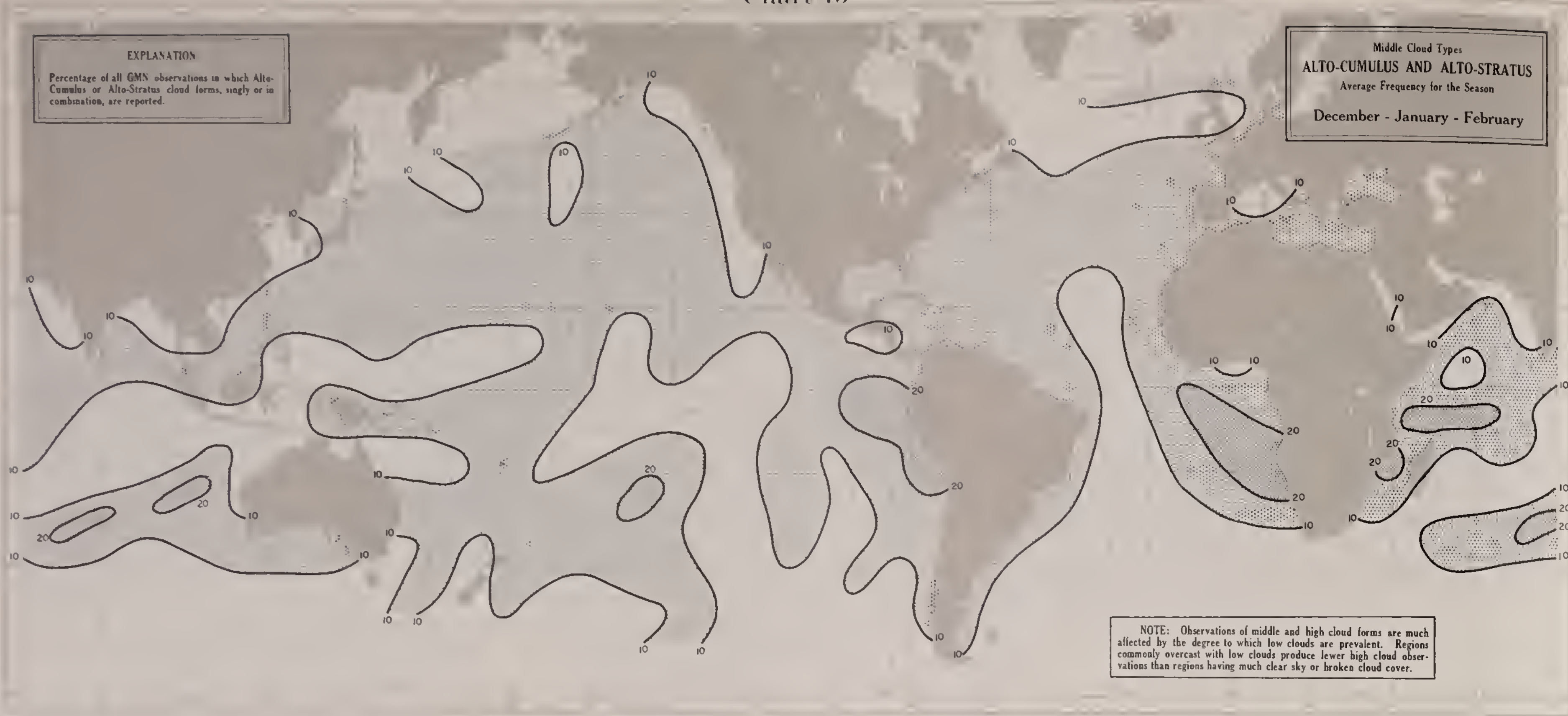

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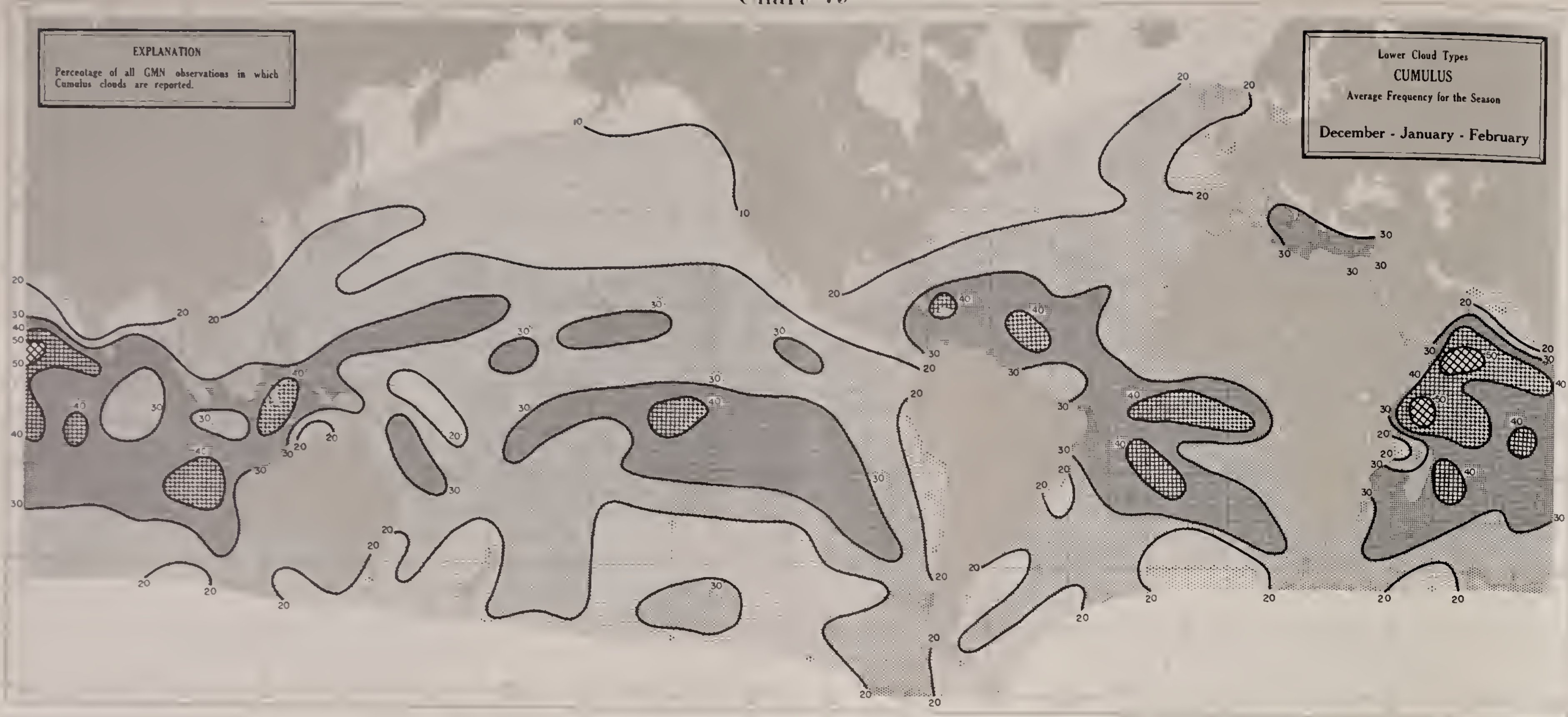

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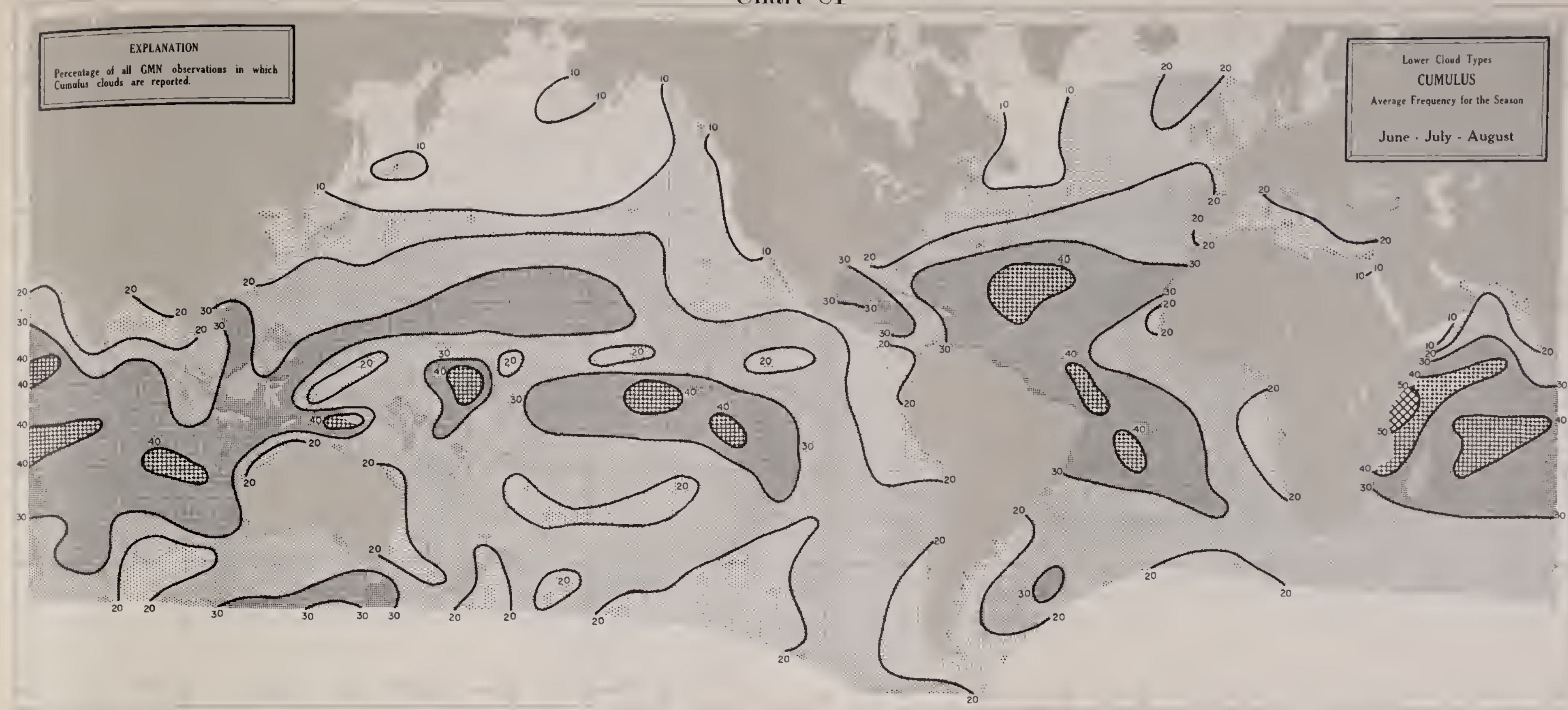

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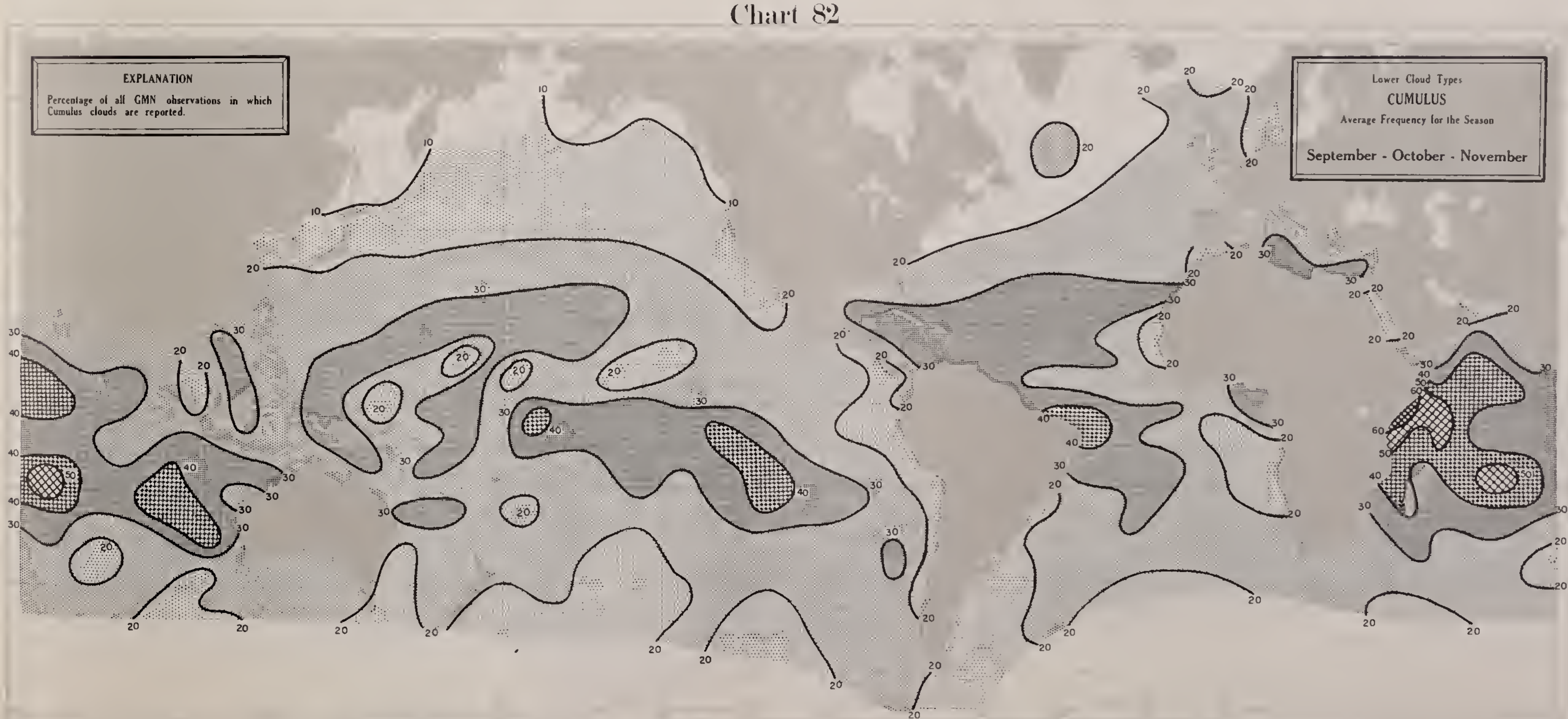

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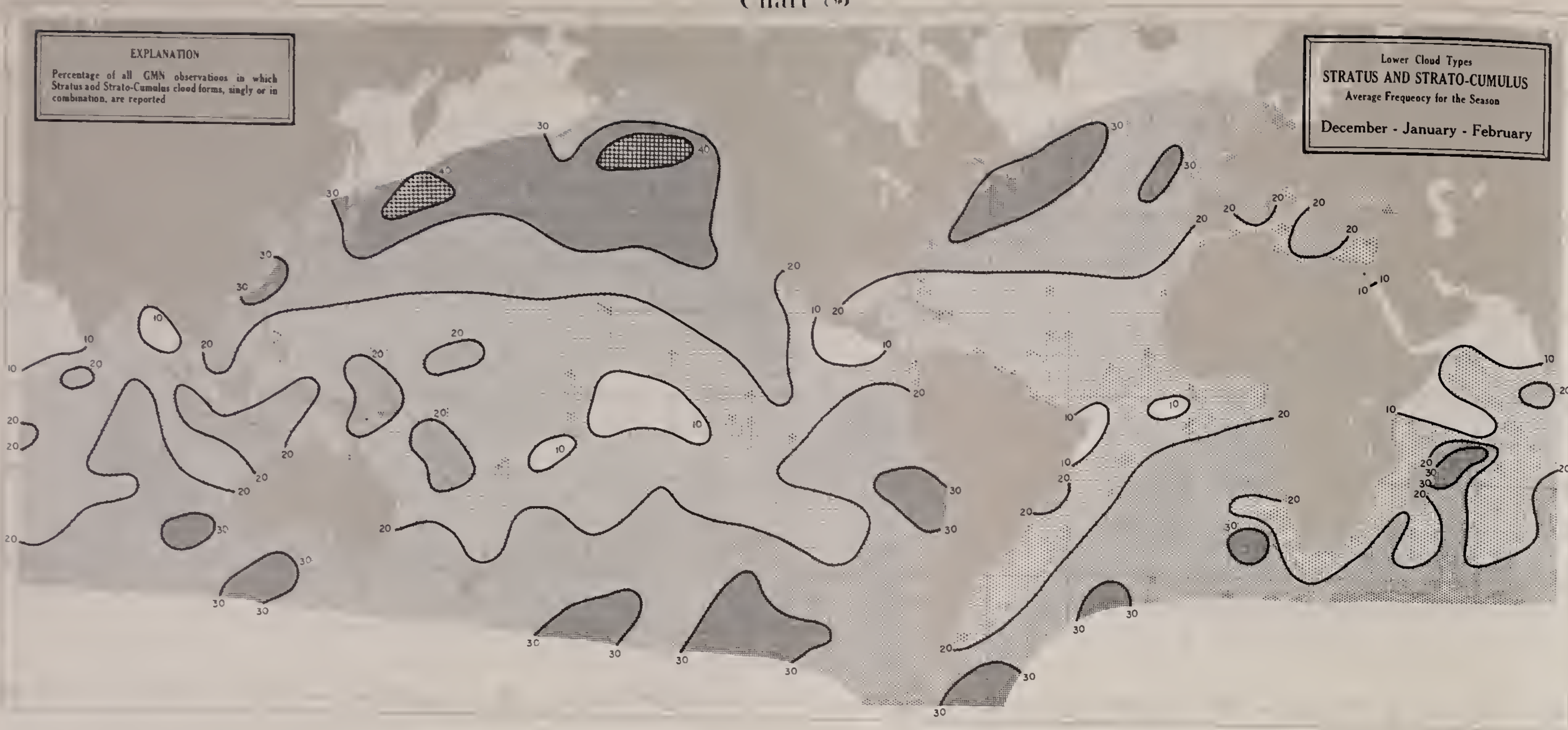

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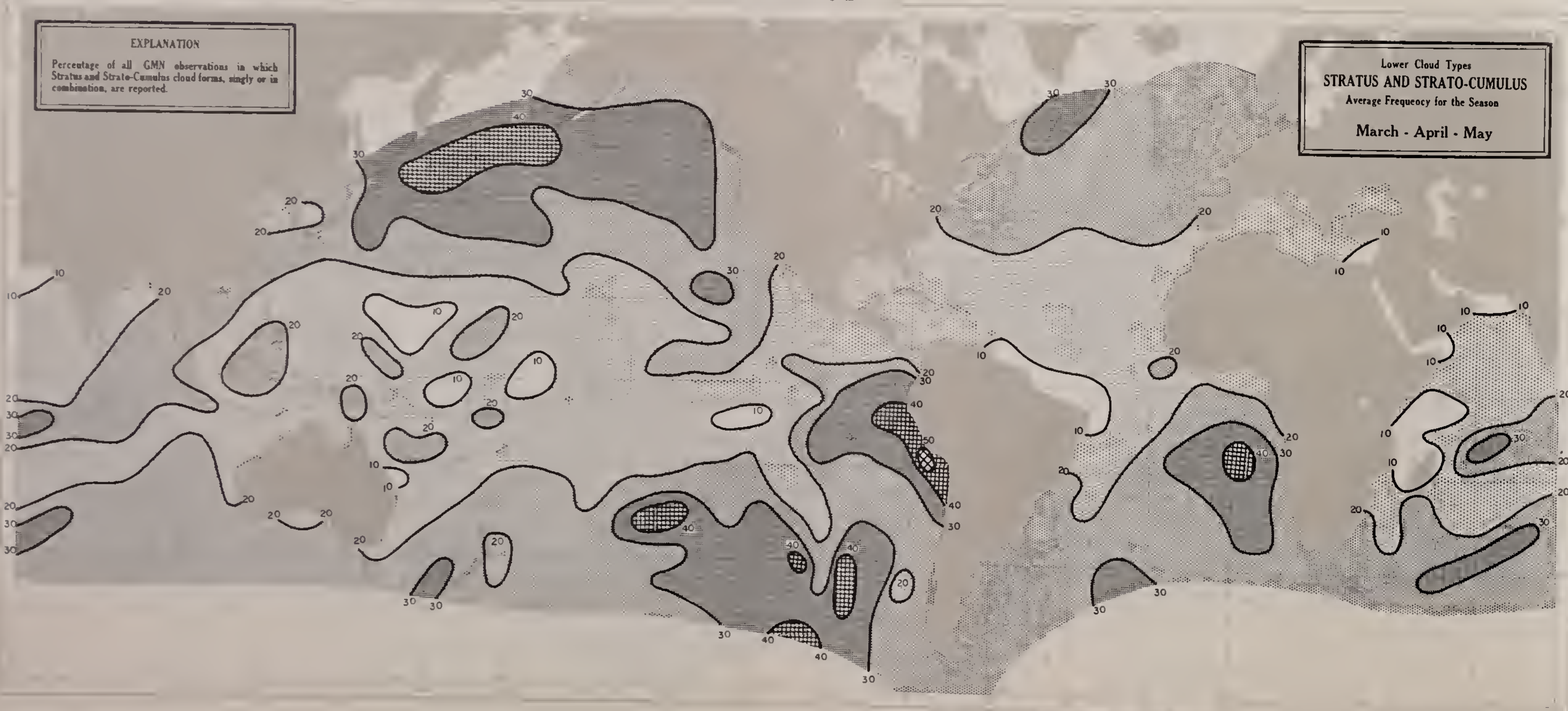

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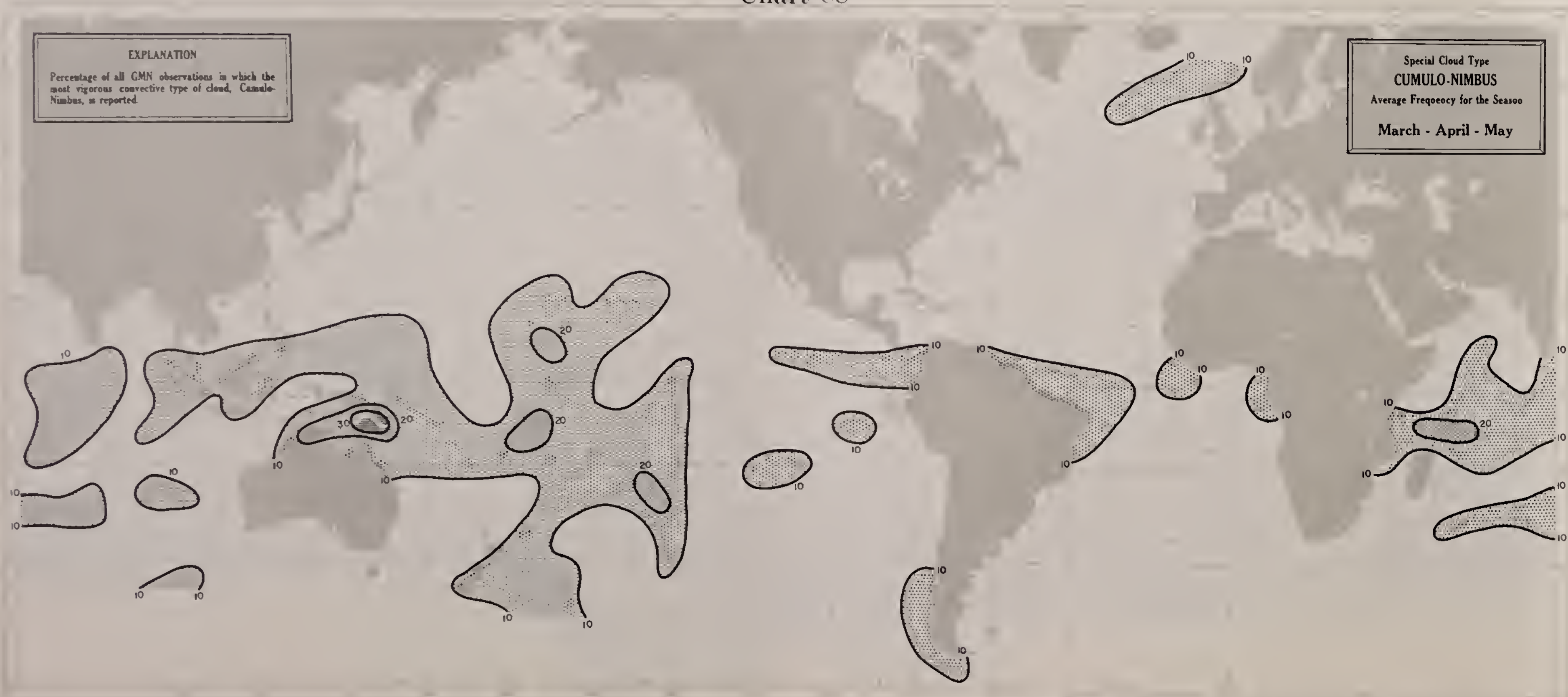

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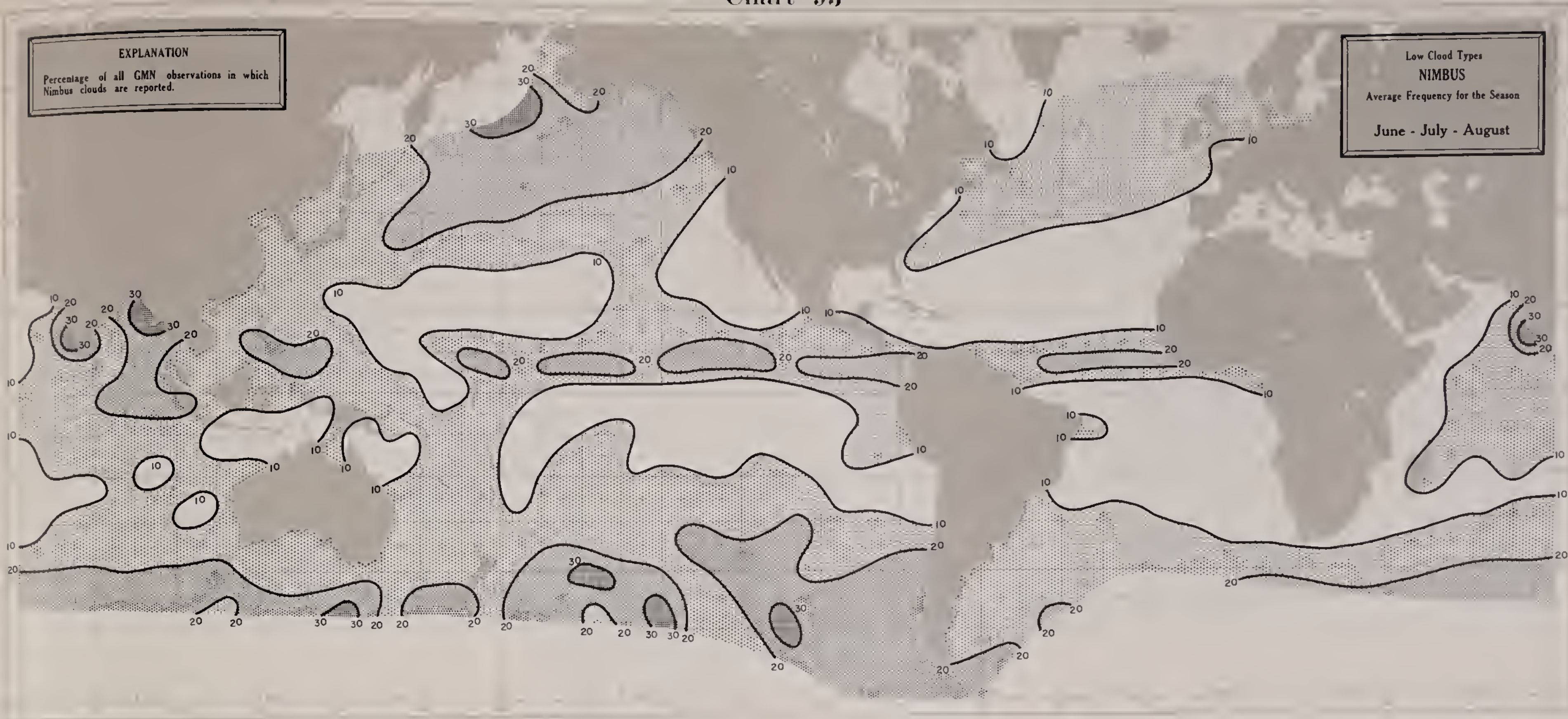

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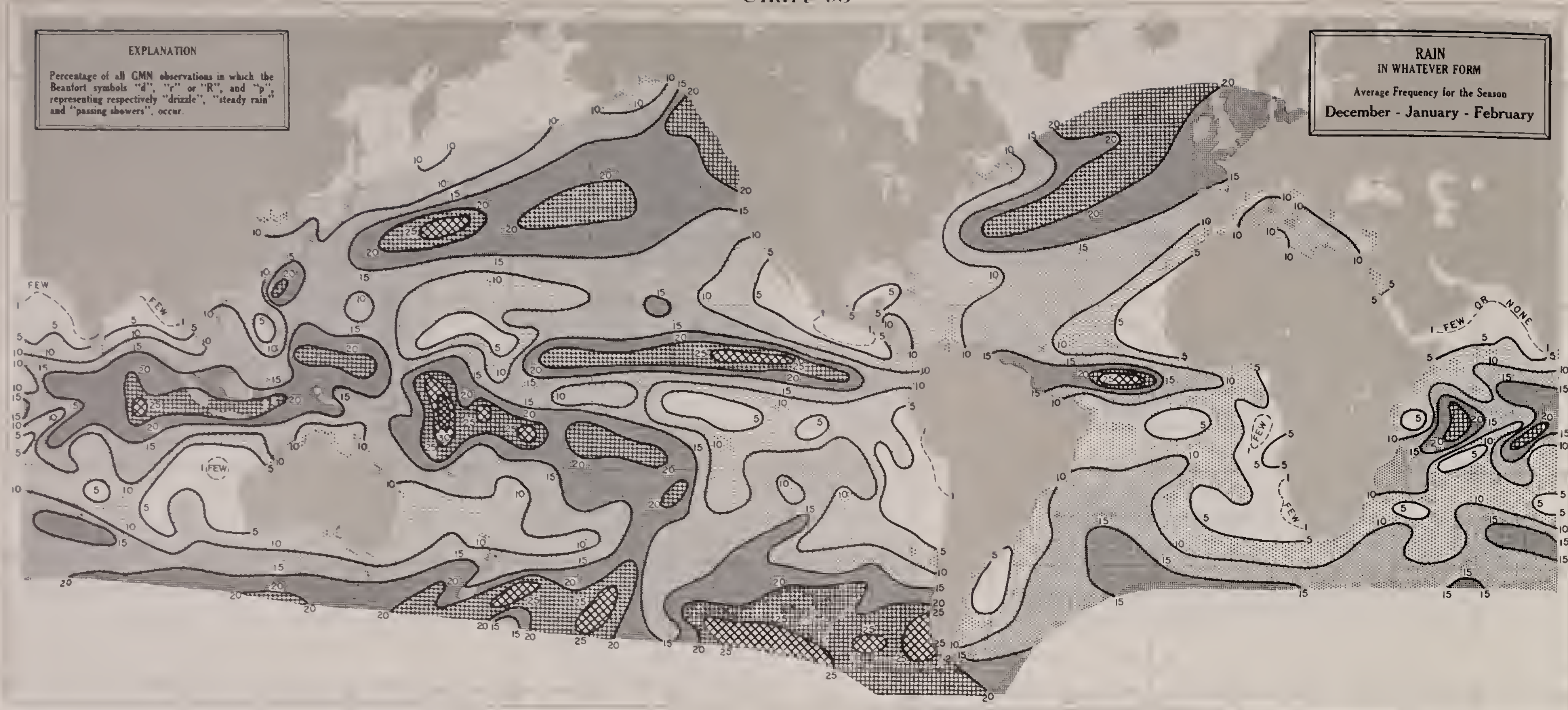

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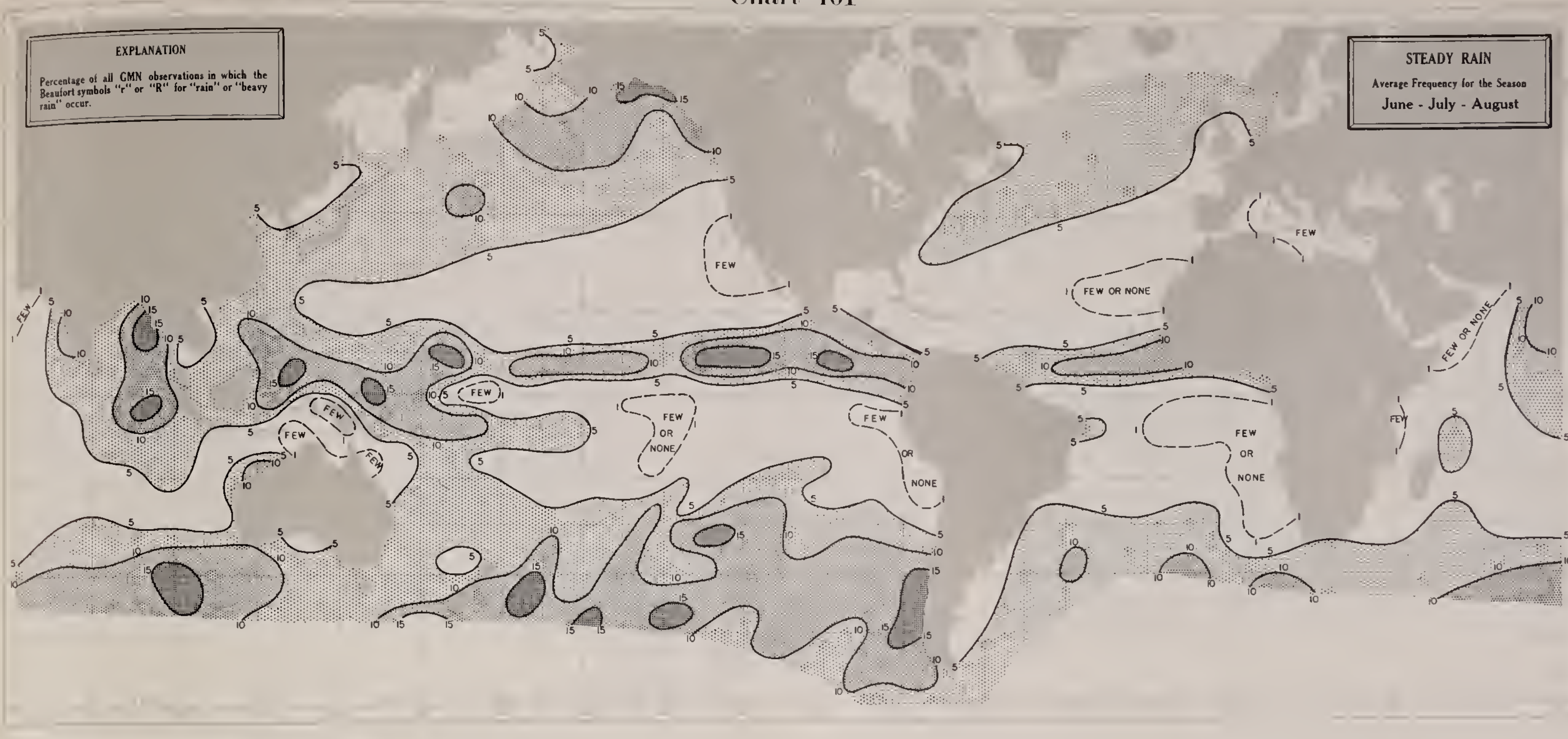

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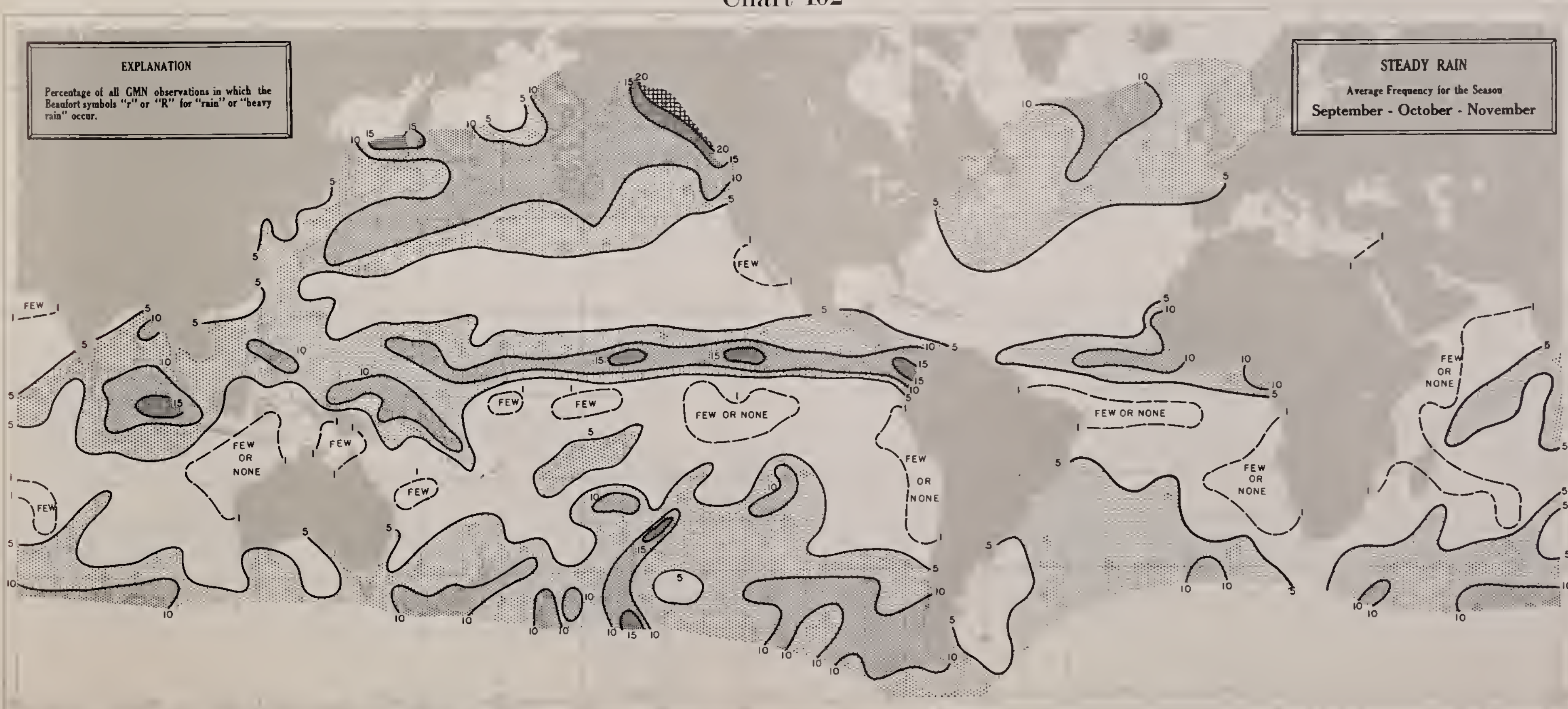

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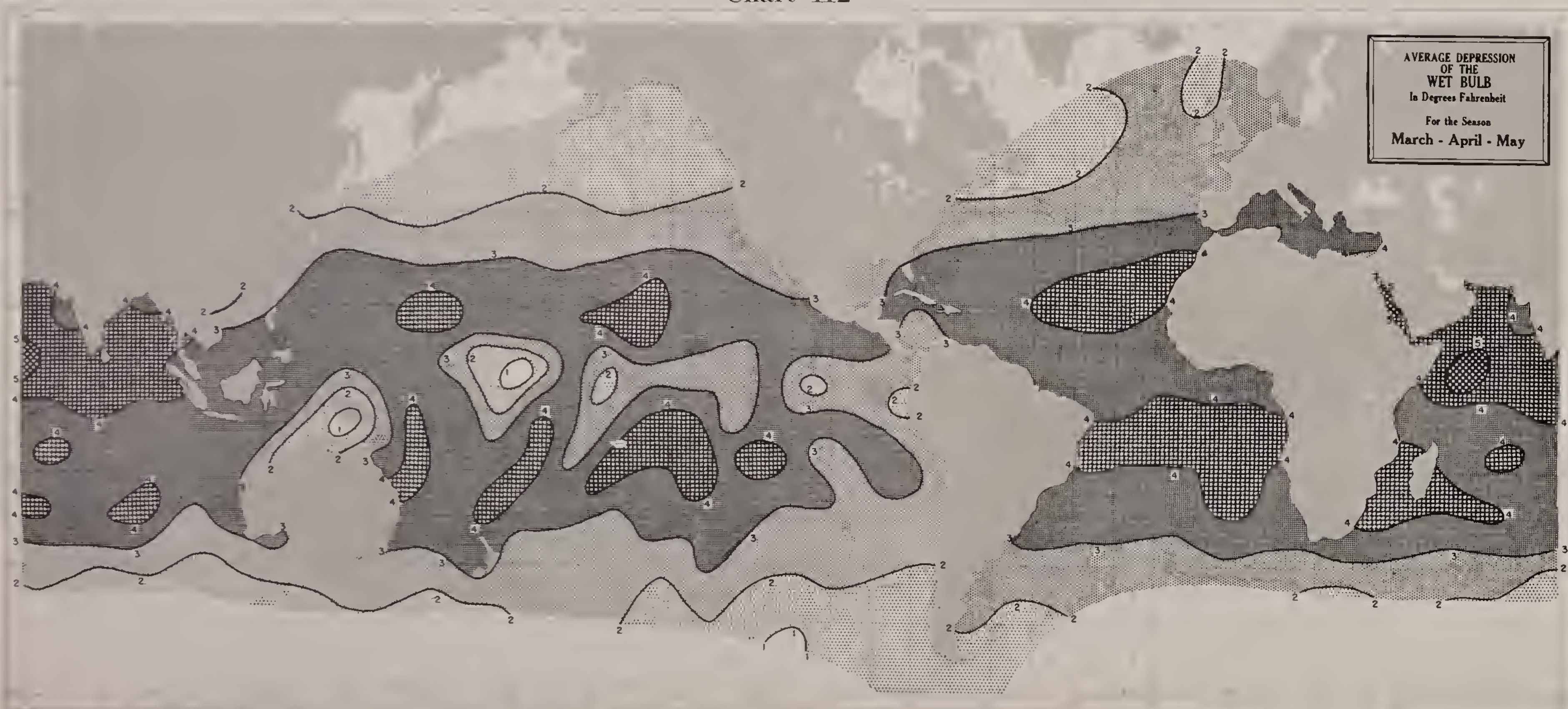

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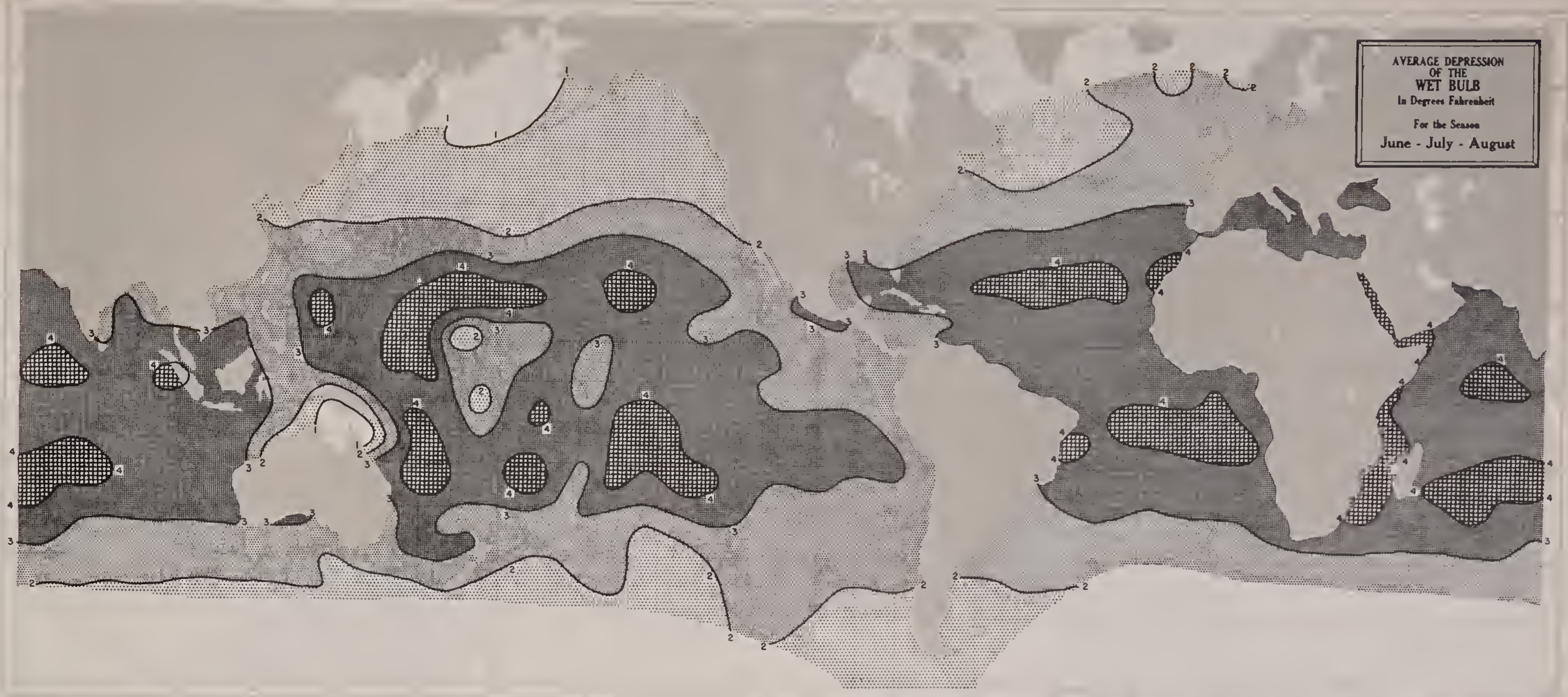

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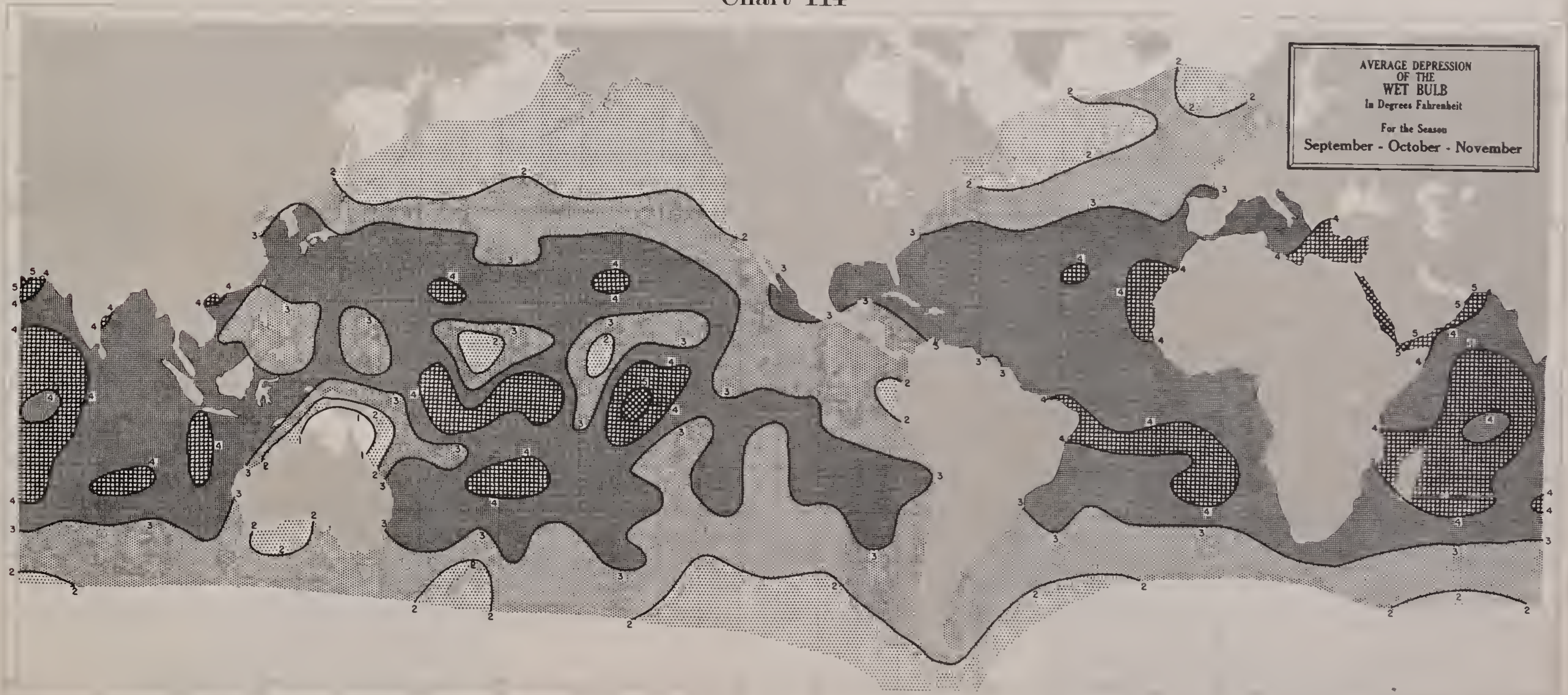

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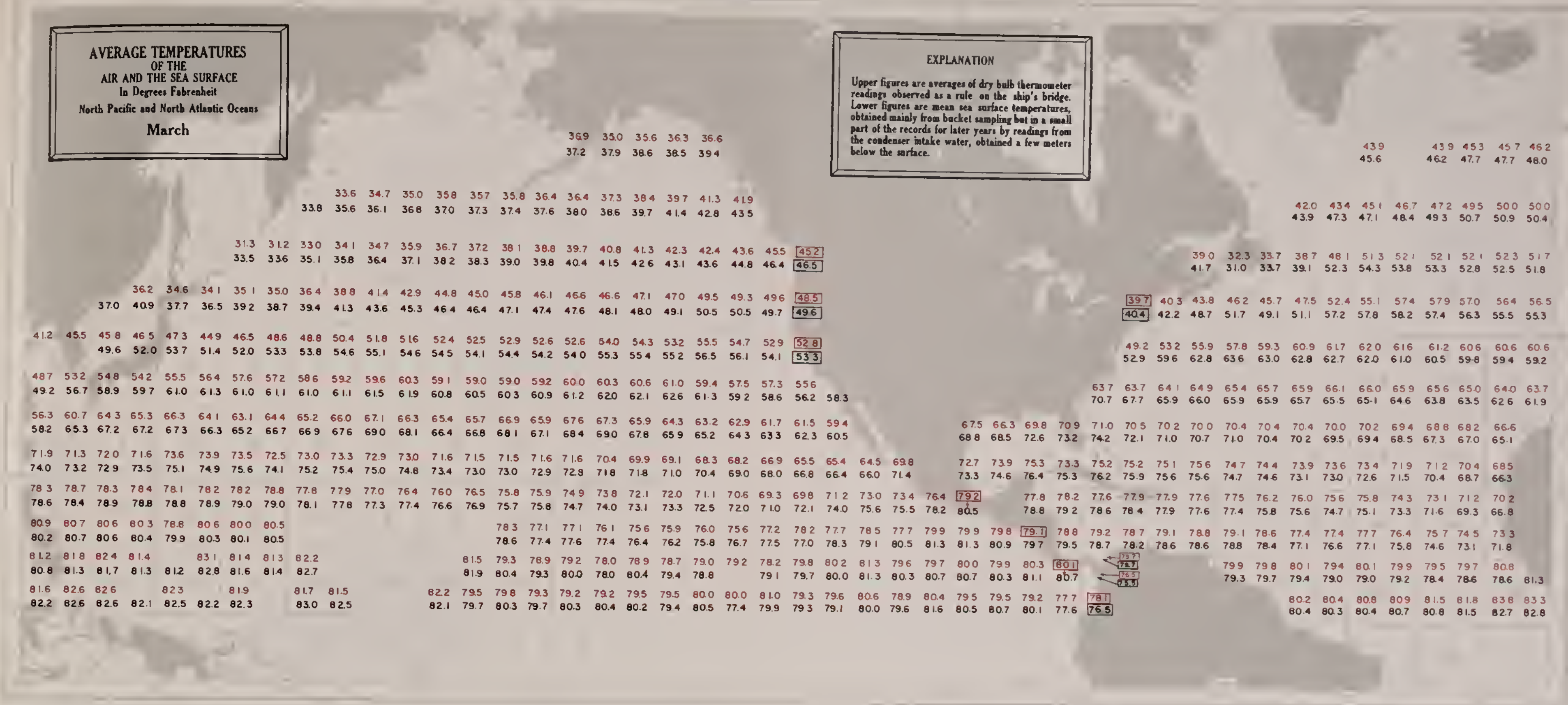

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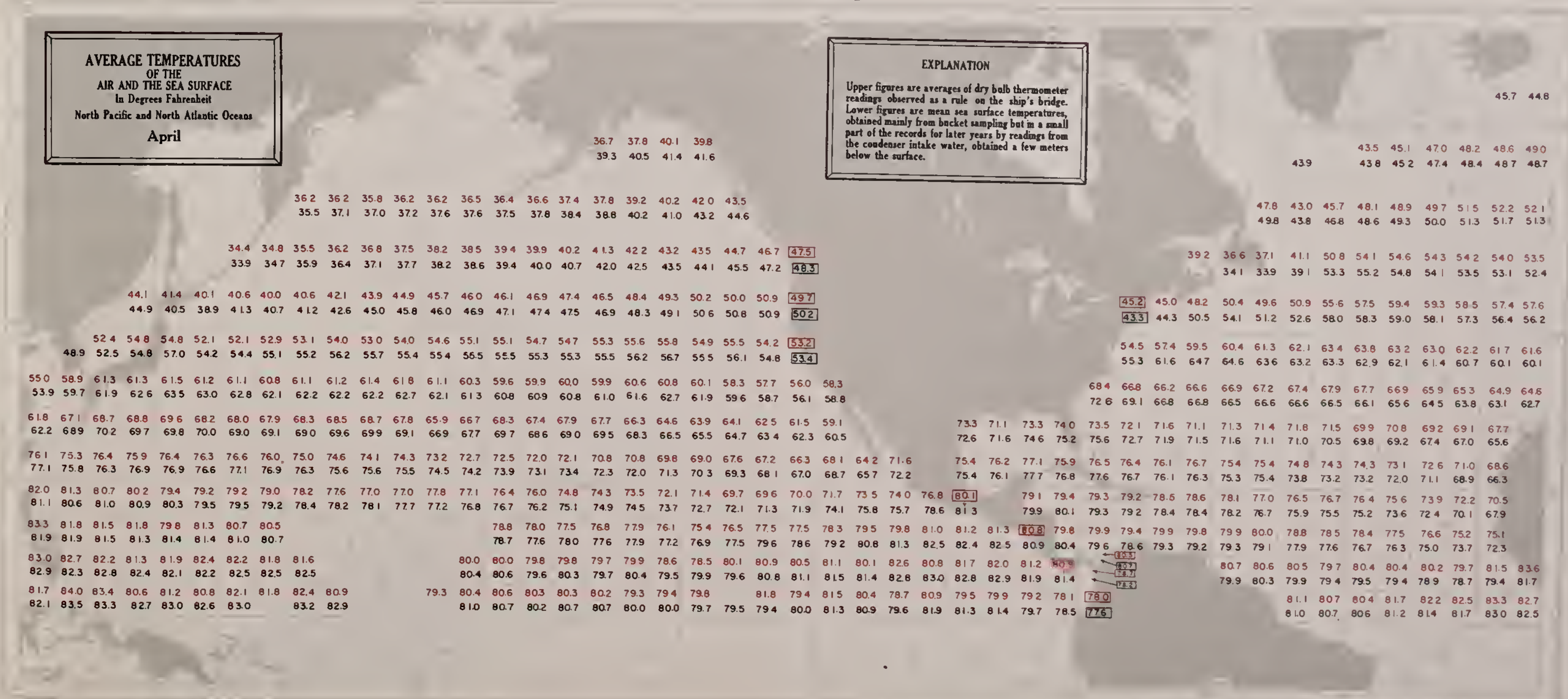

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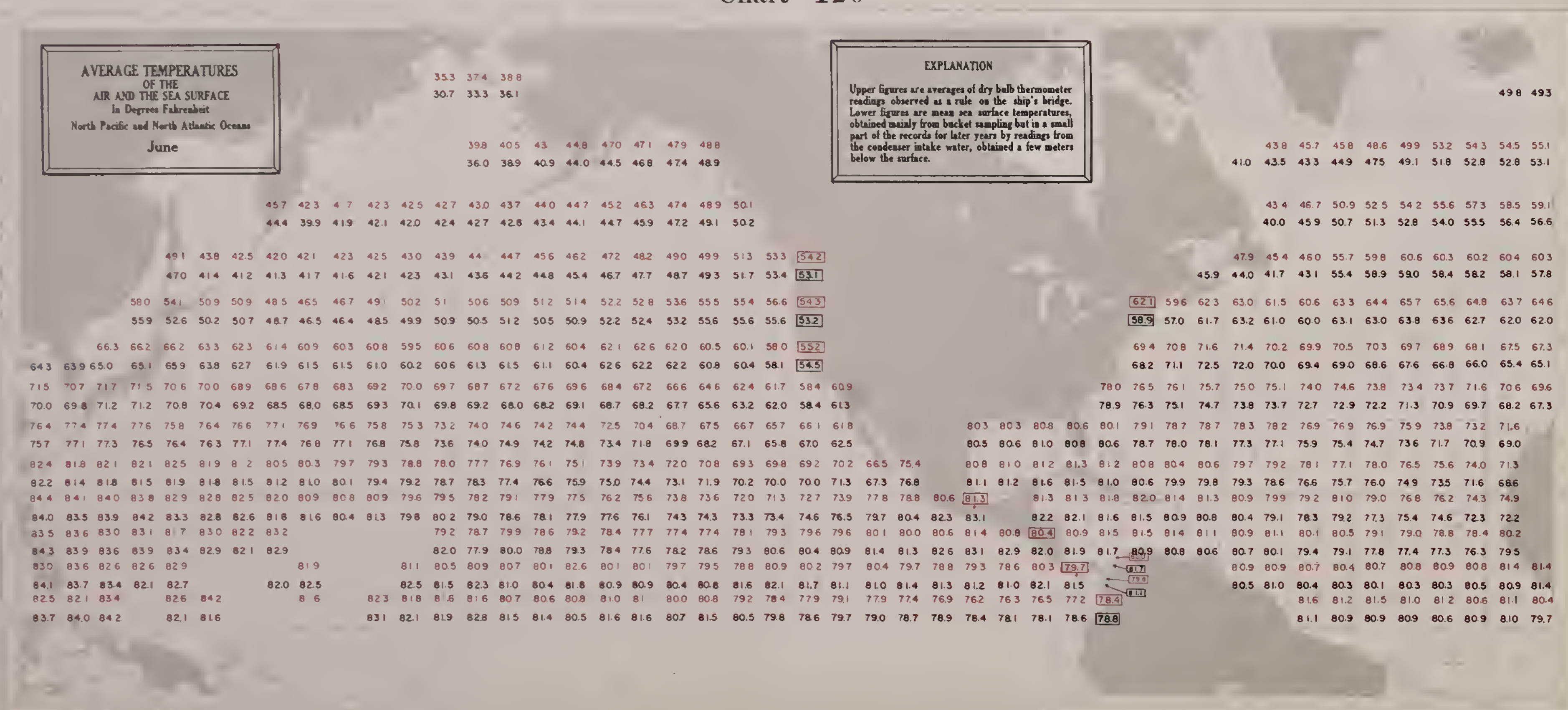

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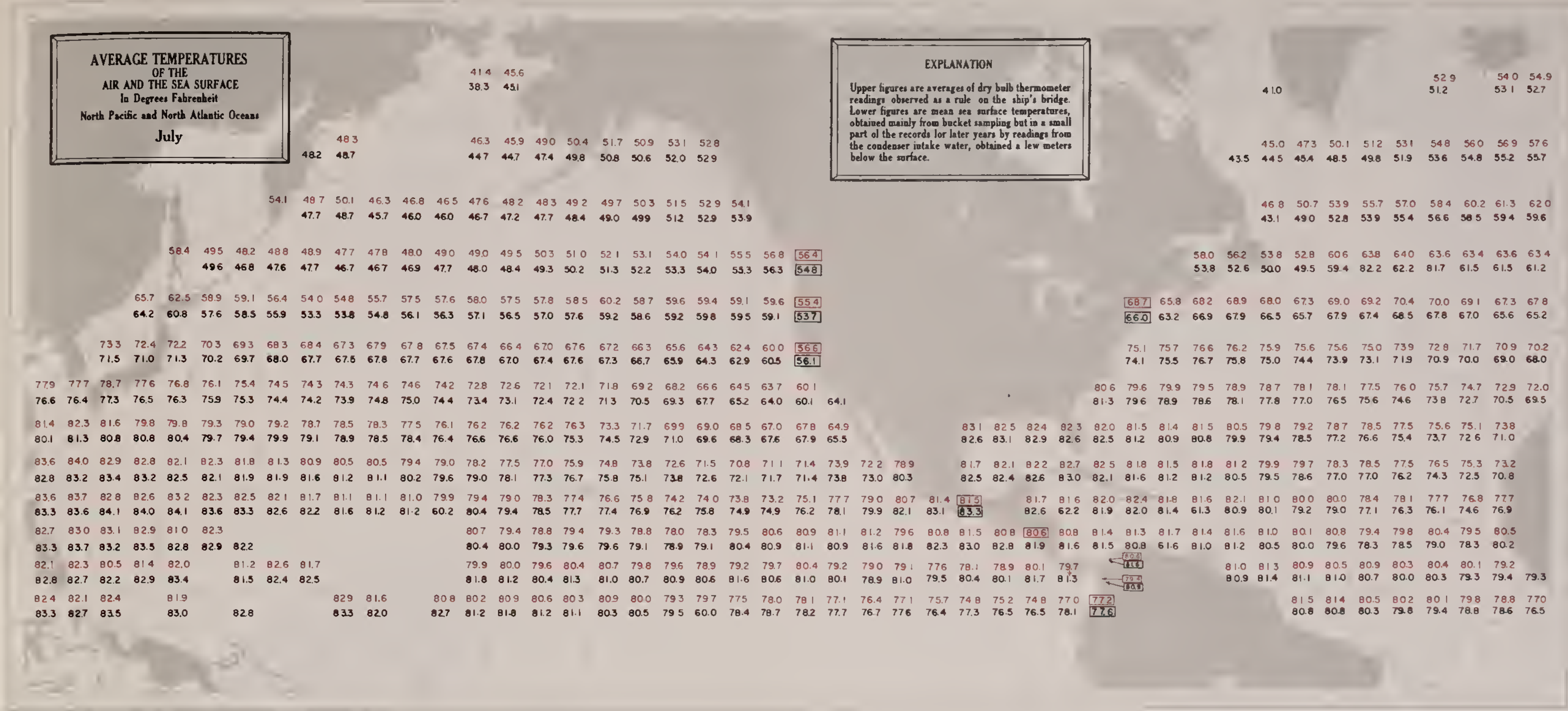

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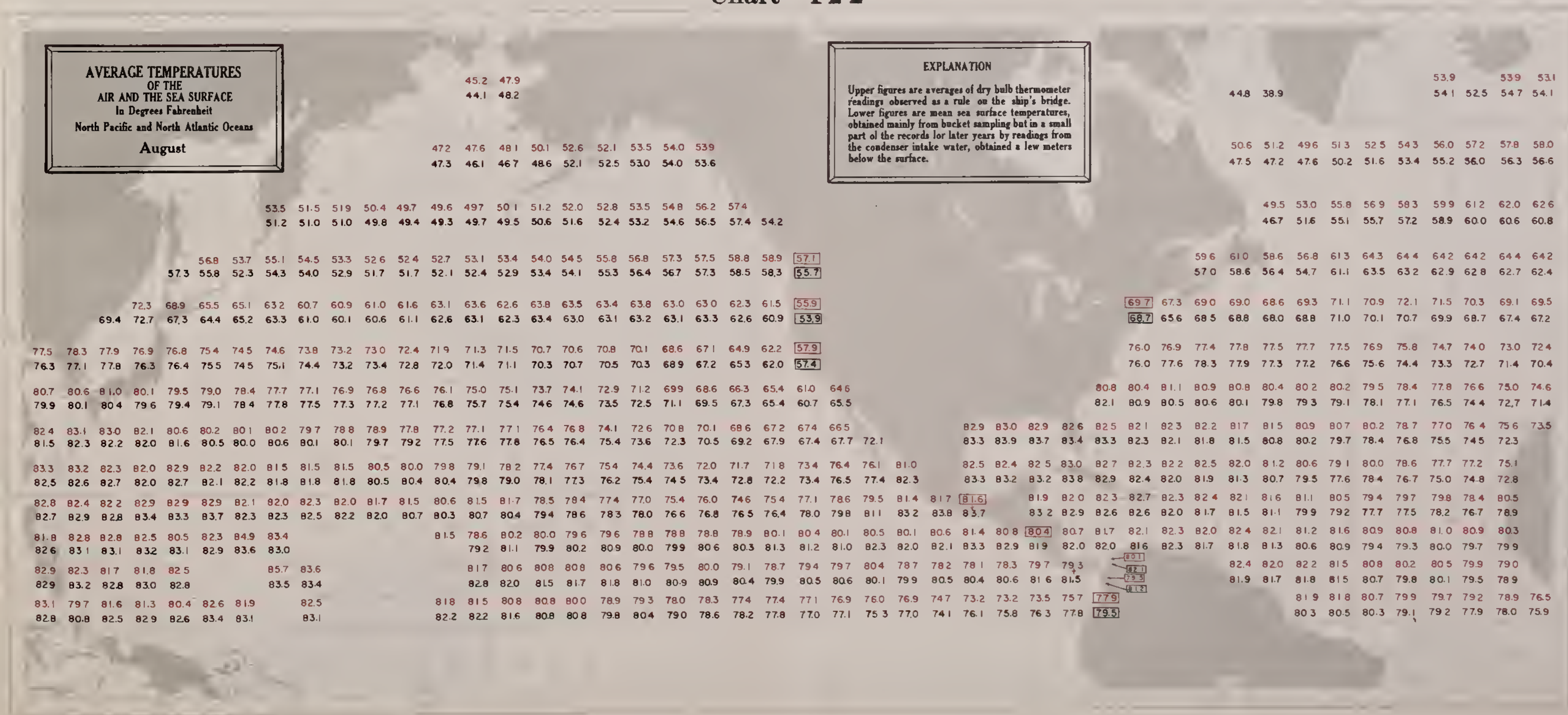

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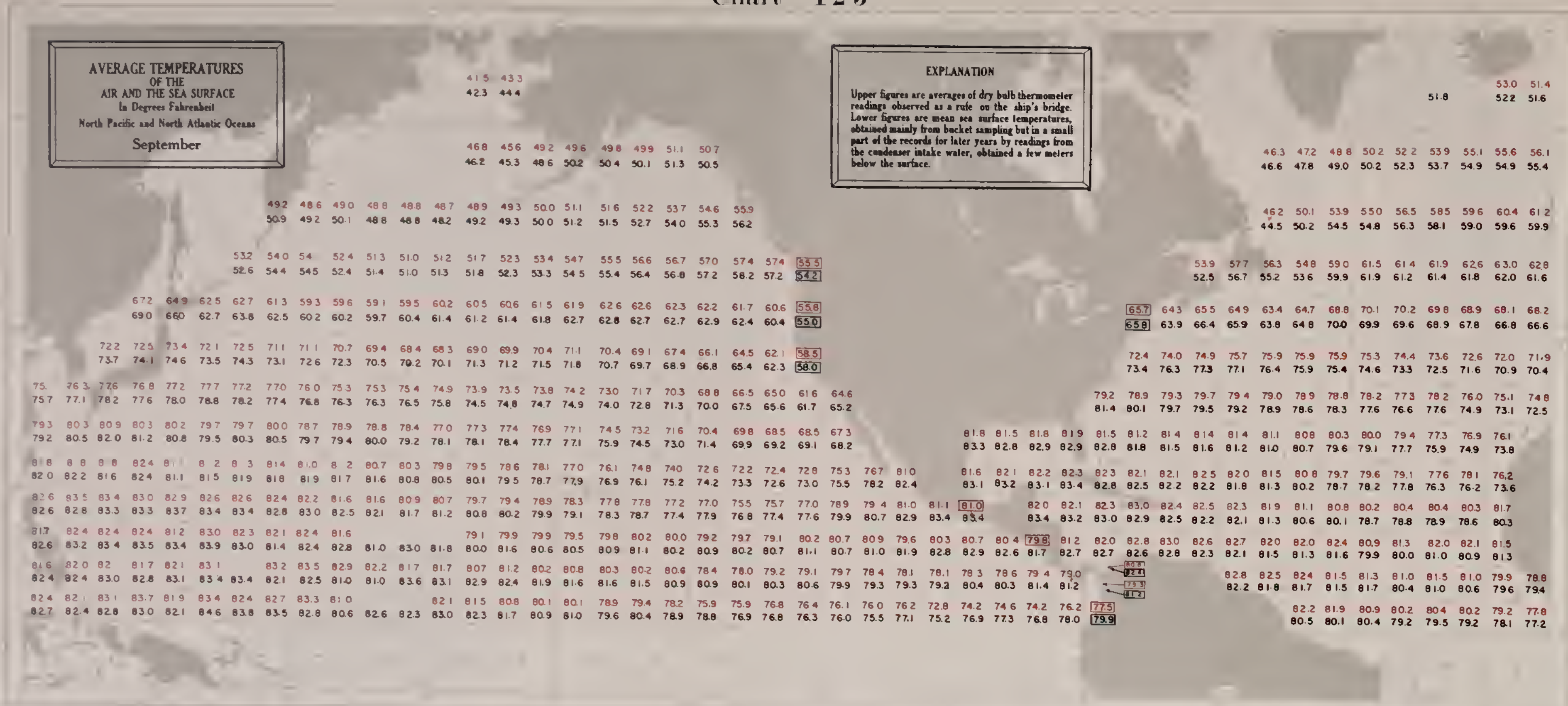

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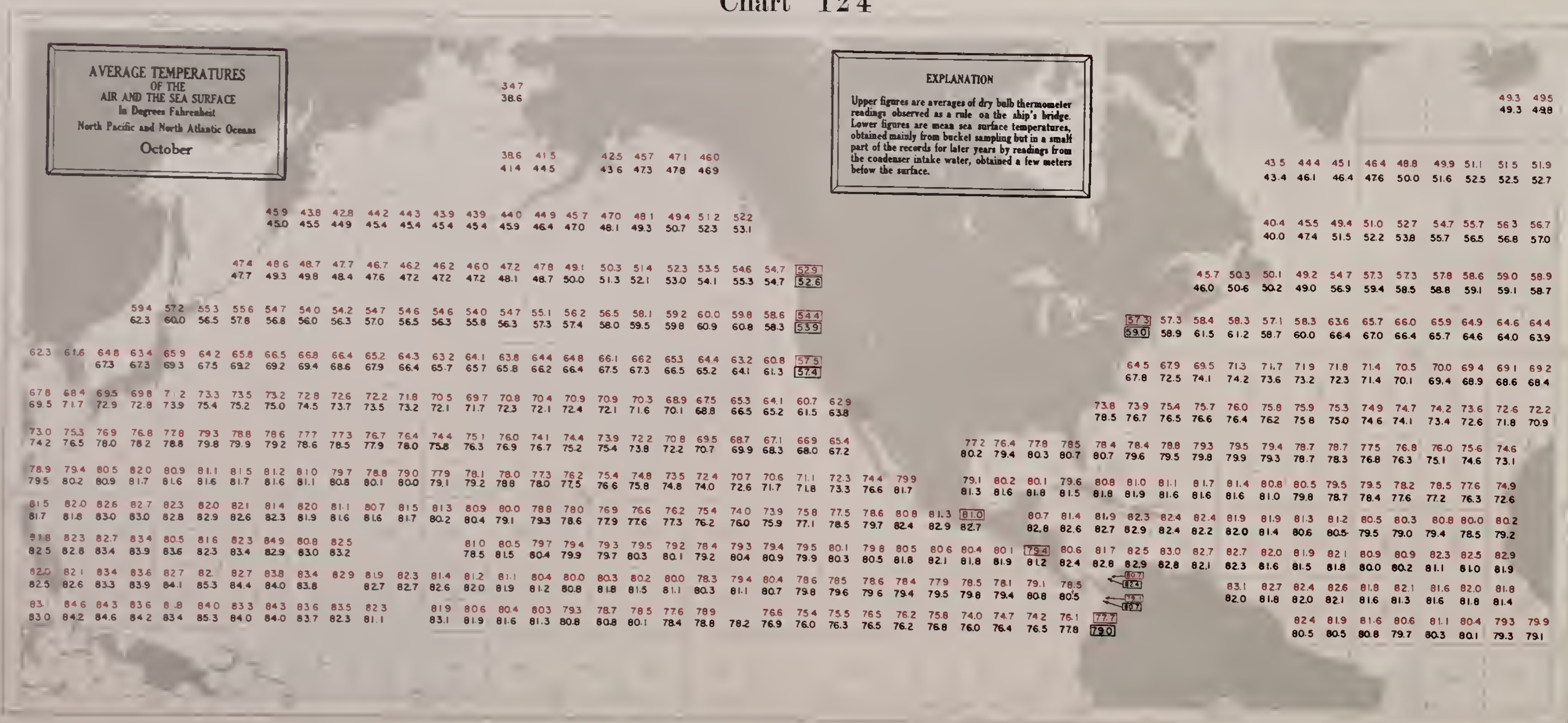

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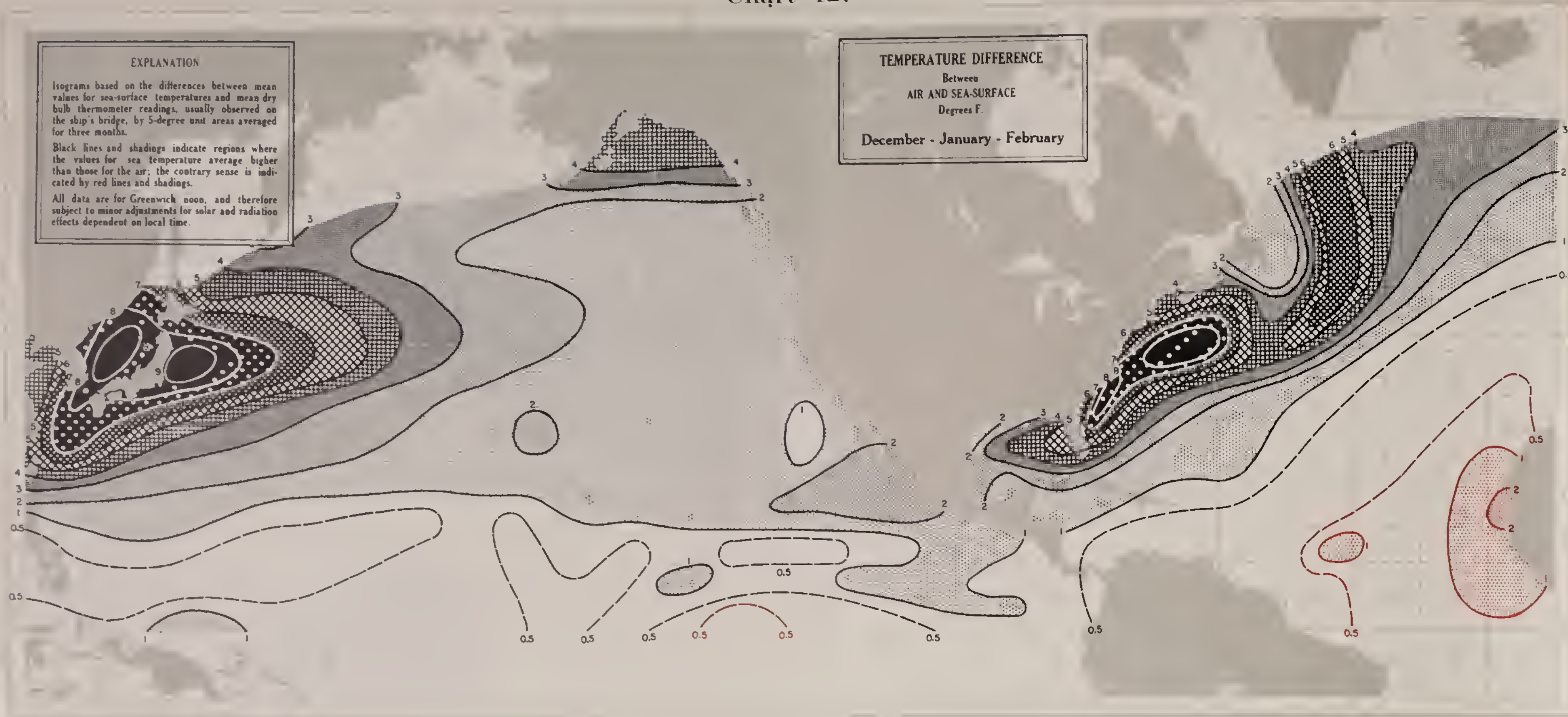

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